Faculty of Electrical Technology and Engineering

DEVELOPMENT OF SOLAR POWERED SOILLESS PLANT CULTIVATION SYSTEM USING IOT APPLICATION

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Bachelor of Electrical Engineering Technology with Honours

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**A project report submitted
in partial fulfillment of the requirements for the degree of
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DECLARATION

I declare that this project report entitled Development of Solar Powered Soilless Plant Cultivation System using IoT Application is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Student Name : Devaaprasad a/l Sivalingam

Date : 2Jan 2025

DEDICATION

This project is fully dedicated to my beloved parents, my father, Mr Sivalingam, and my mother, Ms Devi, whose unconditional love and sacrifices have been the cornerstone of my journey. I also extend my heartfelt gratitude for my supervisor, Ts. Saleha Binti Mohamad Saleh, for her invaluable guidance, support, and encouragement throughout this whole project. This work is a testament to the unwavering belief and support I have received from all of you.

ABSTRACT

There is growing demand for sustainable and space-efficient agriculture operations due to the increase in urbanization and the resulting loss of forest. The aim of this project is to develop a small-scale, solar-powered soilless cultivation system that is affordable for any household. The principal objective is to facilitate plant cultivation in the absence of soil or expansive land areas, hence mitigating the obstacles associated with the scarcity of green spaces in urban settings. The suggested method makes use of Internet of Things(IoT) technologies to track and manage plant growth conditions from time to time. Temperature level, humidity level and pH levels are all monitor by sensor in the system to guarantee ideal growing conditions. The main processor of the system is an ESP32 microcontroller, which processes sensor data and triggers automated actions. The entire system is powered by a solar panel, making it energy-efficient and sustainable. The research methodology involved designing and building a prototype of the hydroponic system, followed by a series of tests to evaluate its performance. Data were collected on plant growth rates, system efficiency, and energy consumption.The findings suggest that such a system can effectively address the need for sustainable urban agriculture, providing a viable solution for households to grow plants in limited spaces. Future research could explore scaling the system for larger applications and integrating additional sensors for enhanced monitoring and control.

ABSTRAK

Terdapat permintaan yang semakin meningkat untuk operasi pertanian yang mampan dan cekap ruang disebabkan oleh peningkatan dalam pembandaran dan mengakibatkan kehilangan hutan. Matlamat projek ini adalah untuk mewujudkan sistem penanaman tanpa tanah berkuasa solar berskala kecil yang mampu dimiliki oleh mana-mana isi rumah. Objektif utama adalah untuk memudahkan penanaman tumbuhan tanpa ketiadaan tanah atau kawasan tanah yang luas, dengan itu mengurangkan halangan yang berkaitan dengan kekurangan ruang hijau dalam persekitaran bandar Kaedah yang dicadangkan menggunakan teknologi Internet of Things untuk menjejak dan mengurus keadaan pertumbuhan tumbuhan dari semasa ke semasa. Pemproses utama sistem ialah mikropengawal ESP32, yang memproses data sensor dan mencetuskan tindakan automatik Seluruh sistem dikuasakan oleh panel solar, menjadikannya cekap tenaga dan mampan sistem, diikuti dengan satu siri ujian untuk menilai prestasinya. Data dikumpul mengenai kadar pertumbuhan tumbuhan, kecekapan sistem, dan penggunaan tenaga.Penemuan menunjukkan bahawa sistem sedemikian dapat menangani keperluan untuk pertanian bandar yang mampan dengan berkesan, menyediakan penyelesaian yang berdaya maju untuk isi rumah menanam tumbuhan di ruang terhad. Penyelidikan masa depan boleh meneroka penskalaan sistem untuk aplikasi yang lebih besar dan menyepadukan penderia tambahan untuk pemantauan dan kawalan yang dipertingkatkan.

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LIST OF SYMBOLS

v	-	Voltage
a	-	Current (measured in amperes, A)
W	-	Power (measured in watts, W)
°C	-	Temperature (measured in degrees Celsius)
pH	-	pH value (acidity or alkalinity measurement)

LIST OF ABBREVIATIONS

V	-	Voltage
IoT	-	Internet of Things
LDR	-	Light Dependent Resistor
DHT	-	Digital Humidity and Temperature Sensor
pH	-	Potential of Hydrogen (measure of acidity/alkalinity)

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CHAPTER 1

INTRODUCTION

1.1 Background

In the era characterized by rapid population growth, urbanization, and environmental issues; hence, increasingly calling for sustainable and efficient agricultural practices. Traditional farming practices come with a set of limitations, such as land and water resource constraints, and the dependence on chemical inputs which has prompted the search for possible alternatives. One of such potentials is the growth of hydroponics, or we can call as as soilless cultivation. For example, soilless cultivation cropping is generally referred to as the growing of plant in a nutrient water solutions rather than in soil, with its advantages of using less land and avoiding further loss of soil. But most of the conventional hydroponic systems are so reliant on grid electricity that it limits poor farmers from the utilization of this technology, which affects sustainability, especially in off-grid or underdeveloped areas.

Monitoring and Control is a key enabling era for the deployment of renewable electricity structures in agricultural manufacturing machines. One of the tracking and controlling machines in agricultural manufacturing machine is greenhouse meals manufacturing that frequently termed managed surroundings agriculture (CEA) which commonly accompanies hydroponics. Several research have proven that soilless cultivation have primary necessities of cultivation, there are growing medium, mineral nutrients, nutrient solution, temperature, water, mild and air as proven.

In the study hydroponics Versatile System to Study Nutrient Allocation and Plant Responses to Nutrient Availability and Exposure to Toxic Elements (2016) by Nga T. Nguyen, Samuel A. McInturf, and David G. Mendoza-Cózatl [1], the authors highlight the advantages of hydroponic systems in plant biology research. These systems are beneficial for precise control of nutrient media, making them ideal for studying plant responses to both essential nutrients and toxic elements.

Hydroponic allows for convenient and cost-effective setup using readily available materials, and is especially useful for experiments requiring intact root systems for downstream applications Due to the excessive electricity demands, improved energy performance studies for soilless cultivatiion can be determined on. One viable manner to make business soilless cultivation a more sustainable and appropriate opportunity might be to relocate the greenhouse to a place in which there are cheap, and renewable reasserts of electricity, such as sun, geothermal or wind energy.

In this project, a prototype of automation for soilless cultivation machine with the use of sun energy as renewable electricity supply is proposed. In this prototype, several parameters are measured to manipulate the soilless cultivation machine and solar energy electricity. The parameters that are measured for managing and tracking the soilless cultivation machine are temperature, humidity, nutrient solution. For solar energy electricity, the parameters that are measured for manage and tracking are voltage and contemporary from the solar panel machine.

1.2 Problem Statement

Traditional cultivation systems are good in terms of maintaining high water uses efficiency and more crop yield. Traditional cultivation systems have a few limiting factors which are not allowing them to be widely adopted. The other limitations of convention systems include high reliability on grid electricity, because of which they cannot be used or sustained in places with low power infrastructures. Next, the efficiency of conventional soilless cultivation setups normally limited by the absence of real time monitoring, which prevents us from adjusting environmental parameters in response to feedback of plants. Low agricultural yields, inefficient uses of resources, and a higher chance of plant stress and disease are the outcomes of this. Besides, the inability to effectively control the pH levels in traditional soilless cultivation systems pose a significant challenge.

Rapid infrastructure and building development results in the loss of forest, green lands and natural ecosystems, which lowers biodiversity and the amount of forest cover. Access to conventional farming techniques becomes scarce in this urban environment, particularly for town or apartment dwellers who don't have enough land for farming. In the study analyzing hydroponic rack system for apartment house (2016) by Mohd Hafiz Talib, Khairul Aidil Azlin Abd Rahman, and Shahrizal Dollah from University Putra Malaysia [2], the authors highlight the benefits of hydroponic systems for urban living spaces like condos and apartments.

The compact design is space-efficient, making it suitable for areas with limited space Next, for this problem innovative solution are required to support the plant production in urban area in order to solve this urgent problem and lessen the detrimental environmental effects of urbanization. By enabling soilless plant growth , which is soilless cultivation system present a viable options for urban agriculture by enabling the cultivation of plants in constrained areas like rooftop, balcony, or even indoors.

Finally, to overcome this problems and to unlock the full potential of soilless cultivation , there is a need for innovative ways and solutions which combine renewable energy sources with advanced monitoring . By developing a solar-powered innovative soilless plant cultivation system integrated with iot based sensors, this project aims to provide a sustainable and efficient alternative to traditional way of soilless cultivation, particularly in off grid or remote areas and in urban areas.

Furthermore, according to United Nations of Malaysia this project aligns with Sustainable Development Goals (SDGs) .The use of solar power supports SDG 7 (Affordable and Clean Energy). By harnessing renewable solar energy, the system reduces reliance on conventional power grids, lowering energy costs and minimizing environmental impact. This not only makes the system more sustainable but also promotes the adoption of clean energy solutions in everyday applications.

In summary, this project offers a sustainable solution for urban agriculture by integrating IoT and solar power into a small-scale hydroponic system. It addresses the challenges of current hydroponic systems and aligns with key SDGs, contributing to the fight against poverty, the promotion of clean energy, and the conservation of terrestrial ecosystems.

1.3 Project Objective

The main aim of this project is to propose as:

I. To develop a prototype an IoT Solar Powered Soilless Cultivation System
II. To design a system that control the IoT Solar Powered Soilless Cultivation System

based on the temperature, humidity, pH sensor ,water level ,current sensor and LDR sensor.

III. To analyze and optimize the performance of the system by integrating various sensor to ensure precise and efficient monitoring and control.

1.4 Scope of Project

The scope of this project are as follows:

I. To design a system that control the IoT Solar Powered Soilless Cultivation System based on the temperature, humidity, ph sensor,water level and ldr sensor using deep water culture method.

II. Integrate Internet of Things (IoT) technology to enable time to time readings update.

III. Utilize a solar panel as the primary power source to ensure energy efficiency and sustainability.

IV. Use lettuce as the primary plant for soilless cultivation system

V. Design the system to be compact and space efficient making it suitable for urban households.

VI. Automating the control of water pumps, pH pumps, and LED grow lights to maintain optimal growing conditions for plants, promoting sustainable and energy-efficient practices through the use of solar power

VII. Designing the system to cater to urban residents living in apartments or small spaces, providing them with an affordable and sustainable solution for growing fresh produce indoors.

VIII. To make it as a market-ready potential product.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This literature review chapter focuses on overall concept and theorie and method of the development of solar powered innovative soilless plant cultivation system. The main aim of this chapter is to clarify related studies and jurnal in the past 5 years. The concept and theory used to solve the projects problems and lackings were discussed in this chapter. The primary sources of information are journals , articles, and case studies. All these resources were chosen based on similar project scope.

2.2 Type of Soilless Cultivation System

There are few types of cultivation system. This chapter will explain every one of them in detailed and dig deep into soilless cultivation system methods and suggested plants for optimal output.

2.2.1 Drip System

The drip system is among the more widely used hydroponic systems. It is more versatile and incredibly simple to enlarge to hold more plants. This system is simple to construct and operate since it has few moving parts. Fundamentally, this system functions by sprinkling a solution over the surface of growing medium that houses the plant. Large volumes of water are not required because the solution is being dropped. Drip lines, which could vary in length and drop different amounts of the solution, can also be extended to encompass a larger area.

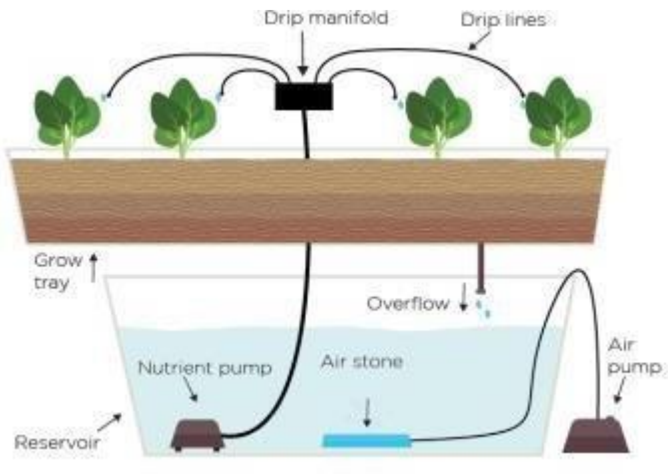

Figure 2. 1 Drip system

2.2.2 Ebb Flow/ Flood & Drain

According to Muhammad Daud(2020)[4] the flood and drain hydroponic system, also referred to as ebb and flow, functions by intermittently inundating the growing medium with a nutrient solution and subsequently draining it away. It typically comprises a cultivation tray or vessel filled with a growing substrate like gravel, perlite, or coco coir, along with a submersible pump, a reservoir holding the nutrient solution, and a timer for regulating the flooding and draining sequences. This setup facilitates adequate aeration to the roots during drainage, preventing water saturation and encouraging robust root development. Moreover, it enables efficient absorption of nutrients by the plants and can be automated for simplified upkeep, rendering it a favored option among hydroponic cultivators.

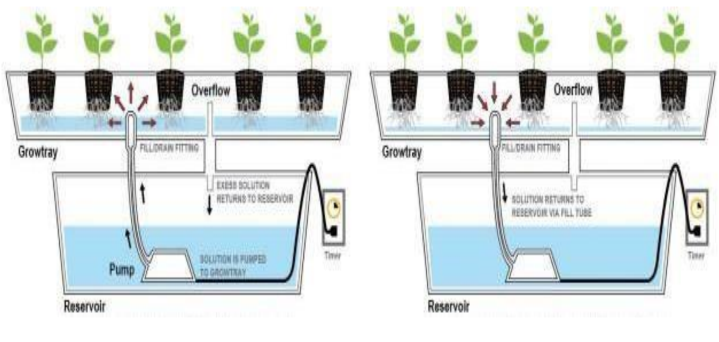

Figure 2.1 Ebb flow system

2.2.3 Nutrient Film Technique

The nutrient film technique (NFT) hydroponic system is a method of growing plants where a thin film of nutrient-rich water flows continuously over the roots of the plants, usually contained within a shallow channel or gutter by Chris Mullins (2022)[5]. The roots are suspended in the stream of nutrient solution, allowing them to absorb the necessary water and nutrients directly. This method ensures that the roots have access to a constant supply of oxygen while avoiding waterlogging, promoting healthy growth and efficient nutrient uptake. NFT systems are popular in hydroponic cultivation due to their simplicity, water efficiency, and suitability for growing a wide range of crops.

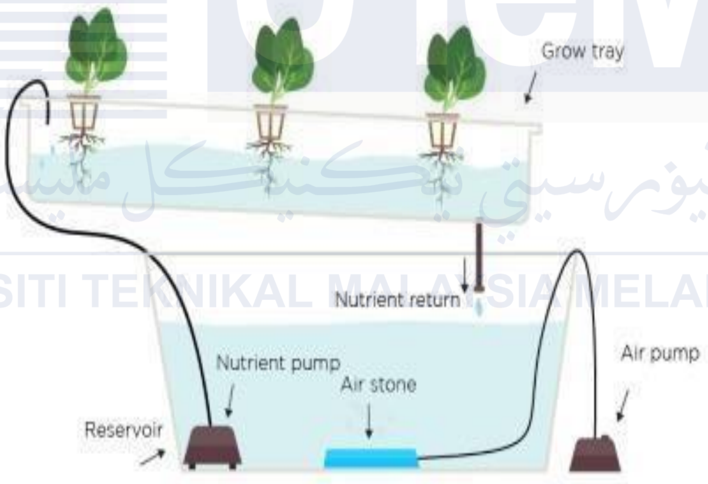

Figure 2.2 Nutrient film technique

2.2.4 Water Culture

The water culture technique is a hydroponics method in which plant is grown directly in a nutrient solution without the use of a solid medium like soil or gravel. On this system, plant roots are submerged in the nutrient solution, allow them to directly absorb water and essential nutrients. The nutrient solution is aerated to ensure an enough supply of oxygen to the roots. This method is straightforward and cost-effective, making it suitable for growing leafy greens and herbs. So, it requires careful monitoring of nutrient levels and pH to prevent nutrient deficiencies or imbalances.

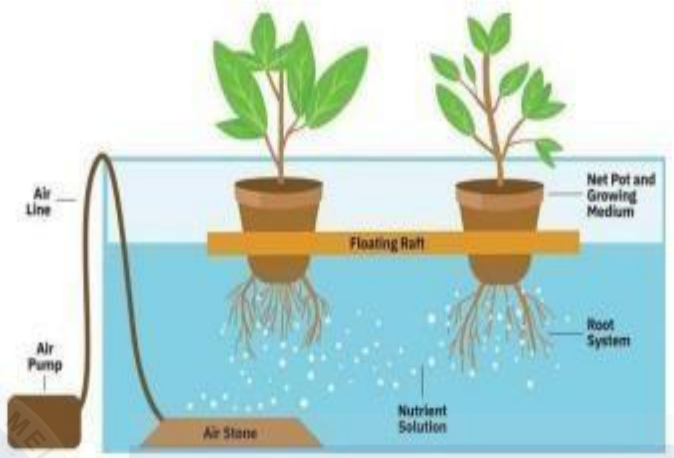

Figure 2.3 Water culture

2.2.5 Aeroponic

The aeroponic technique is an advanced hydroponic method that involves growing plants suspended in air, with their roots periodically misted or sprayed with a nutrient-rich solution. Unlike other hydroponic where roots are submerged in nutrient solution, aeroponics allows roots to be exposed to air, promoting oxygen uptake and efficient nutrient absorption. This method provides plants with optimal growing conditions, allowing for rapid growth and high yields. However, it requires precise control of environmental factors such as humidity, temperature, and nutrient concentration, making it more complex and costly to set up compared to other hydroponic systems. Despite the initial costs, aeroponics offers a sustainable solution for high-density farming, especially in urban areas where space and resources are limited. Its scalability and adaptability make it an ideal method for future agricultural advancements, addressing challenges like food security and environmental sustainability.

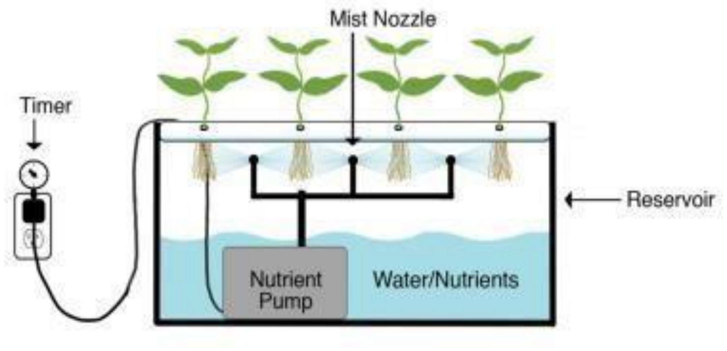

Figure 2.4 Aeroponics

2.2.6Wick System

The wick system technique is a simple and passive hydroponic method where plants are grown without the use of pumps or electricity. In this system, a wick, typically made of cotton or felt, draws nutrient solution from a reservoir and delivers it to the plant's root system. The wick acts as a conduit, allowing the roots to absorb the necessary water and nutrients for growth. While the wick system is easy to set up and maintain, it may not be suitable for large or heavy feeding plants due to its limited nutrient delivery capacity. Additionally, the wick system works best with smaller plants or herbs rather than larger, fruit-bearing crops.

2.3 Review of existing system

This subtopic will explain the journals that have been surveyed to learn more about the soilless cultivation system and how it works with various methods.

2.3.1 Automation system hydroponic using smart solar power plant unit

According to Simon Siregar, Hydroponics automation system is one of the agricultural solutions[6]. This ,have some problem with hydroponics that can be divided into two parts.

The first part is the hydroponics system. The system needs to control and monitor temperature, pH, and water distribution. Some are power supplies and usually need to operate with traditional electrical energy. There are two possible solutions to solve the problem. The first possible solution is automation of hydroponic cultivation system to measure and control temperature and pH and the water level in the water tank. The second possible solution is an intelligent PV unit. It acts as a primary power source and switches to traditional power when: There is not enough power to carry out the automation of the hydroponics system. The power plants unit monitor the intensity of light, voltage and current. The voltage generated by the battery, DC AC converter and solar panel. value temperature , ph, water level, light intensity, current in the tank, the voltage is sent to the server via wireless communication. The result of this study is prototyping hydroponic automation system with monitorable intelligent photovoltaic power plant. It controls pH, temperature, water level, light intensity, current, and voltage.

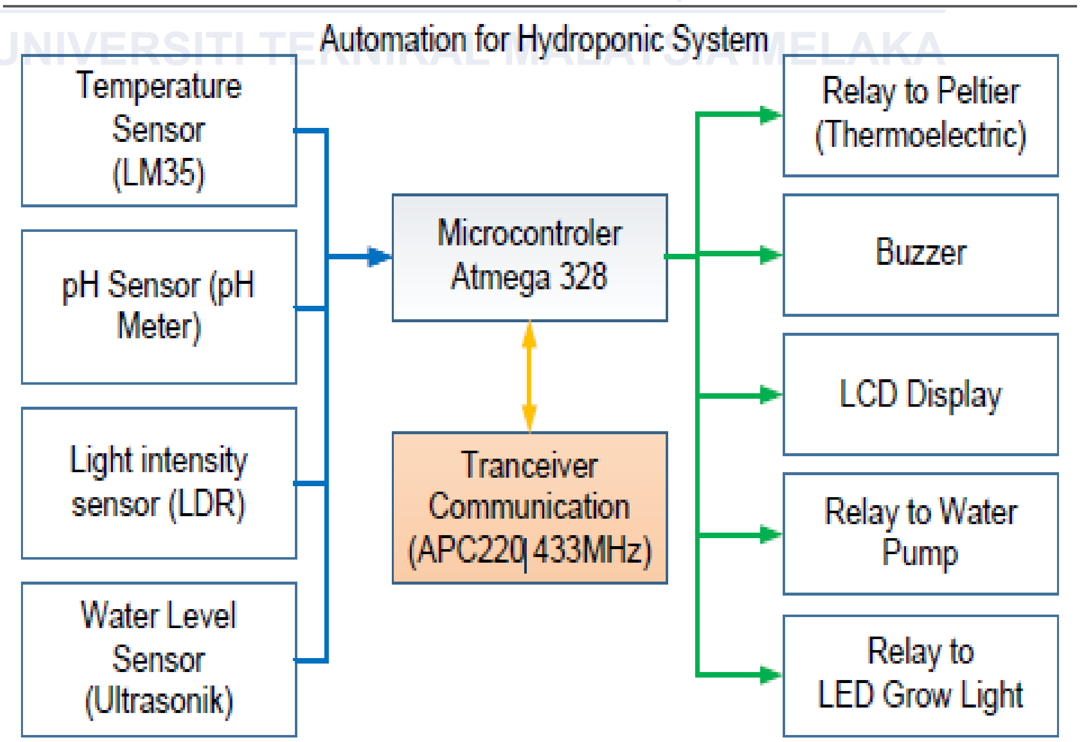

Figure 2.5 Block diagram of system

2.3.2 Automated system developed to control pH and concentration of nutrient

Diego S. Domingues states that Hydroponics has several advantages, including Possibility of use Areas that are not suitable for conventional agriculture [7]. Dry and deteriorated Soil. Harvest weather independence Indian summer, frost, hail, wind, flood, And weather season, enables year-round cultivation. Reduce the use of labor-intensive activities Weeding and soil preparation. Activities in Hydroponics can also be considered mild . In addition to this, there are expectations for harvesting By shortening the plant cycle, showing a fast economy Return , Abandonment of crop rotation , including optimal water and nutrient utilization efficiency, With high environmental benefit. It has also been reported that hydroponics is not just cultivated. Not only related to higher production, but also allows for better control Standardization and reduction of cultivation process.

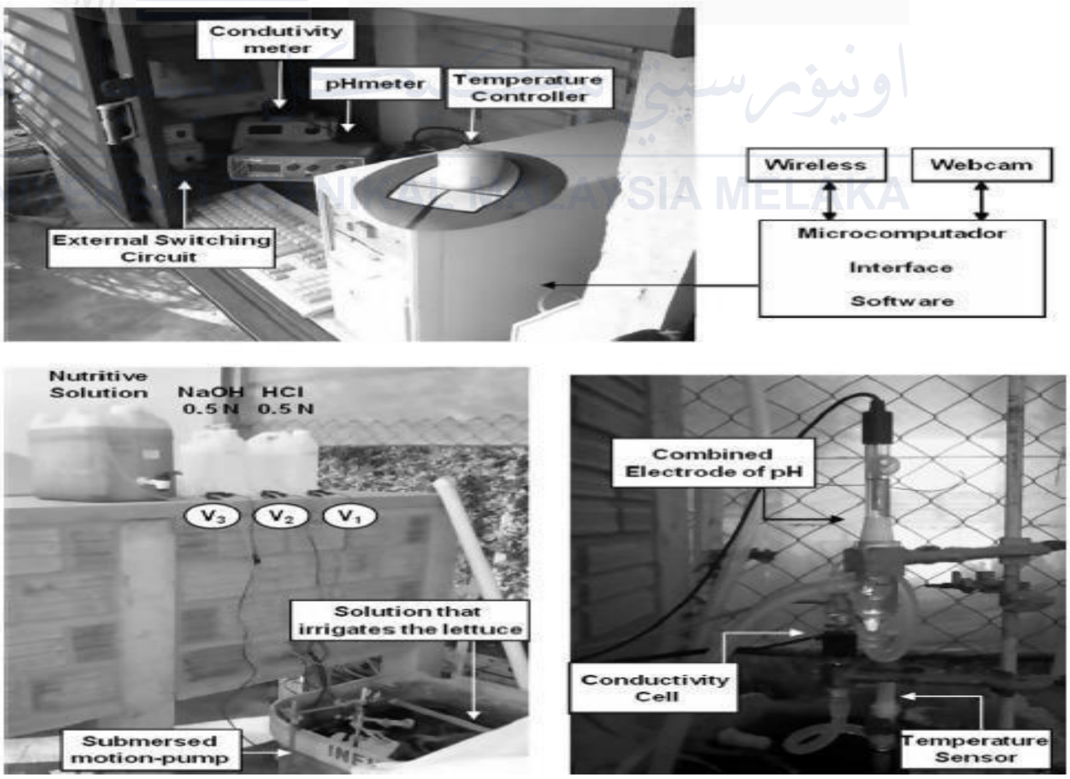

Figure 2.6Automated system developed to control PH and nutrient

2.3.3 Design and Development of Solar Powered Smart Hydroponic

Mr. Parth Varmora proposed that Hydroponics is a new agricultural production system that produces on soilless media with water[8]. Hydroponics systems require less controlled environment for plants to grow properly. Disease risk and faster growth. This includes automatic monitoring and control of the environment Parameters such as temperature, humidity, PH and conductivity. Parameters are recorded by each sensor. When the value is above or below the respective setting, the system will start adjusting. And it tries to reach that face value. The second part of the proposed design is the power supply. The hydroponic greenhouse uses a smart solar power unit that acts as the main power source and switches to traditional power when there is not enough power to perform automation of the hydroponic cultivation system. To provide the primary supply as photovoltaics, it is necessary to monitor the solar panels and battery voltage. Depending on your requirements, the system will switch to the main feed (traditional network). And with this technique You can grow crops such as tomatoes, cucumbers and peppers without the use of harmful pesticides or fertilizers.

2.3.4 Evaluation of the resource use efficiencies of small-scale vertical hydroponic

According to Zikhona Buyeye on 2022, the study investigates the resource utilization efficiency of small-scale vertical hydroponic structures compared to traditional ground-based planting methods[9]. With a focus on land, water, and energy use efficiency under sunlight and LED grow lights, the research aims to assess the potential of small-scale vertical farming systems for agricultural intensification. Findings indicate that vertical hydroponic structures exhibit higher resource use efficiencies than soil planting, with increased agricultural productivity across various metrics. Notably, crop water productivity and energy use efficiency are significantly enhanced in hydroponic systems compared to soil planting. Moreover, while water consumption remains consistent between treatments, significant disparities are observed in crop water productivity. Additionally, energy use efficiency is notably higher in plants grown hydroponically under sunlight compared to those under LED grow lights. These results highlight the promising role of small-scale vertical hydroponic systems in optimizing resource utilization in agriculture, offering a potential solution to conventional farming challenges. The study concludes by emphasizing the significance of vertical farming in enhancing agricultural sustainability and productivity. Acknowledgements extend to financial support from the Agricultural Research Council and the Department of Science and Technology, South Africa, with author contributions encompassing data collection, interpretation, conceptualization, and critical revision of the research article.

2.3.5 Energy Sustainable Hydroponics with Automated Reporting and Monitoring

This project was done by Chris Lopez on 2022, this project use nutrient film technique hydroponic system where a water pumps is use to control the flow of water which passes through the roots of the plants(Nguyen,2022)[10]. The purpose of this to improve the system usability by incorporating touchscreen interface. This project uses a single board computer. This project required the ability to analise sensor data from a standard web browser while also sending control data. The system is designed such that minimal user involvement and attention are required. Everything from nutrient levels to circulation ,water quality,lighting has been automated.

2.3.6 Solar powered IoT smart hydroponic nutrition management system using FARM

Based on W. Wedashwara, the research aims to develop an IoT-based hydroponic system designed to optimize plant growth by monitoring and regulating environmental conditions[11]. The system employs sensors, including DHT11 for temperature and humidity, BH1750 for light intensity, and a TDS sensor for nutrient concentration. Through a microcontroller, these sensors collect data to make decisions such as activating the solenoid valve to drain water or turning on pumps for nutrient delivery, all geared towards stabilizing TDS levels. This research seeks to create an efficient and automated hydroponic setup that ensures optimal growing conditions for plants, contributing to agricultural sustainability and productivity.

2.3.7 Hydroponic Solutions for Soilless Production Systems

Based on Paolo Sambo's research in 2021, the hydroponic project focuses on the crucial role of solution chemistry in hydroponic cultures to ensure proper nutrient concentrations for plant growth[12]. The study emphasizes the significance of considering multiple chemical equilibria, including precipitation, co-precipitation, and complexation, in preparing nutrient solutions using salts or concentrated liquid stocks. Factors such as temperature, pH, and ionic strength are highlighted as key influencers on these chemical processes, which can greatly impact nutrient availability for plants. Additionally, the research underscores the importance of real- time monitoring and control of solution parameters to optimize plant growth and prevent issues such as nutrient precipitation or complexation.

2.3.8 Monitoring System of Hydroponic Using Solar Energy

Based on Muhammad Syahmi Kamarulzaman's project, the methodology involves the deployment of key components such as a solar panel, charger controller, rechargeable battery, Arduino Uno, I2C LCD, temperature sensor, pH sensor, and water level sensor. These components collectively facilitate the hydroponic monitoring system[13]. Solar energy is harnessed by the solar panel, converted into electrical energy, and stored in a 12V battery regulated by a charger controller to prevent overcharging. The charger controller then supplies direct electrical energy to the hydroponic system during the day, while stored energy in the battery serves nighttime operations. Activation of the Arduino for system operation is facilitated by a power supply.

2.3.9 Evaluation of the Resource Use Efficiencies of Small-Scale Vertical

According to Aidan Senzanje's study, the objective was to assess the resource use efficiency of small-scale vertical hydroponic structures in comparison to ground-based planting, specifically regarding land, water, and energy use efficiency under both sunlight and LED grow lights. The motivation behind investigating small-scale vertical farming systems lay in their potential to yield more produce per unit area with lower energy requirements compared to large-scale vertical farming. The study hypothesized that resource use efficiencies in vertical hydroponic structures under sunlight and LED grow lights would not differ significantly from those of soil planting. However, the results disproved this null hypothesis, indicating that vertical hydroponic structures exhibited higher resource use efficiencies than soil planting. The experimental setup included a randomized complete block design with factors such as growing method, light provision, and nutrient solution concentration. The findings suggest that small- scale vertical hydroponic systems hold promise for enhancing agricultural productivity while optimizing resource utilization.

2.3.10 Smart solar powered hydroponics system using internet of things

According to I W A Arimbawa, the focus of the research was on the resource use efficiency of small-scale vertical hydroponic structures compared to ground-based planting, with an aim to assess their potential for agricultural intensification[14]. The study aimed to evaluate land, water, and energy use efficiency under sunlight and LED grow lights. Methodologically, a hydroponic vertical design was chosen, with Swiss chard selected as the test crop due to its adaptability to hydroponic systems. The experiment, conducted over two cropping seasons, utilized a randomized complete block design with factors including growing method, light provision, and nutrient solution concentration. Results indicated higher resource use efficiencies in vertical hydroponic structures compared to soil planting, suggesting their potential for enhancing agricultural productivity while conserving resources.

2.3.11 Water Nutrient Management in Soilless Plant Cultivation versus Sustainability

As explained by Artur Mielcarek, this project focuses on soilless cultivation systems for tomato production, examining their efficacy in delivering nutrients and water while maximizing plant growth. Various techniques, including deep flow, nutrient film, and aeroponics, are explored, each offering unique advantages in terms of root immersion and aeration[15]. Additionally, modern irrigation methods like drip-irrigation and sub-irrigation are discussed, highlighting their precision and efficiency in delivering water and nutrients to the plants. The project underscores the importance of maintaining optimal physicochemical conditions in the nutrient medium to support healthy plant growth and maximize yield.

2.3.12 Pretreated Agro-Industrial Effluents as a Source of Nutrients for Tomatoes

As explained by Alexandra Afonso and collaborators, hydroponic cultivation emerges as a promising solution to tackle challenges posed by climate change and anthropogenic activities, offering benefits such as reduced water consumption and increased productivity[16]. The study explores the use of cheese whey wastewater (CWW) in hydroponic systems after pretreatment, aiming to reduce fertilizer usage and alleviate water scarcity. Different hydroponic setups are evaluated for cherry tomato production, with physicochemical properties and sensory characteristics of the tomatoes assessed. The CWW, collected from a cheese production facility, undergoes pretreatment via immediate one-step lime precipitation (IOSLP) followed by carbonation, resulting in efficient removal of contaminants. The pretreated CWW, supplemented with macro and micronutrients, serves as the nutritive solution for hydroponic cultivation. The study's findings provide insights into the viability of utilizing agro-industrial wastewater in hydroponic systems, offering a sustainable approach to agriculture.

2.3.13 Solar Based Hydroponics Cultivation

According to D. Sarathkumar, the project involves implementing a solar-based supply and automatic control system for water flow in hydroponic plant cultivation[17]. By utilizing solar energy, the system aims to increase plant growth speed while reducing electricity costs and space requirements for cultivation. The proposed system comprises four units which is solar panel, relay, arduino, and pump, controlled through arduino programming. The system operates by harnessing solar energy, converting it into power, and controlling the water flow to the plants based on humidity levels and a timer. The experimental setup focuses on growing plants without soil, utilizing mineral nutrient solutions in water solvents to increase production efficiency by 3 to 10 times compared to traditional soil cultivation methods.

2.3.14 Soilless farming: An innovative sustainable approach in agriculture

According to Yasir Hanif Mir, soilless farming is presented as a solution to the challenges facing traditional soil-based agriculture[18]. The project highlights the limitations of soil, such as susceptibility to biotic and abiotic stresses, and the decline in soil fertility and productivity. With the world's population projected to reach 9.8 billion by 2050, the demand for food production is escalating, yet arable land is diminishing due to urbanization and industrialization. In regions like Kashmir, agricultural land is shrinking at an alarming rate, exacerbating concerns about food security. Climate change further complicates these challenges, affecting natural resource availability and posing threats to human health and sustainability. Soilless farming emerges as a promising alternative, offering controlled environments for crop growth and year-round production with minimal water and nutrient usage. Despite its advantages, soilless farming requires careful consideration due to technical requirements, initial investment, and ongoing surveillance of plant growth parameters.

2.3.15 Soilless Cultivation: Dynamically Changing Chemical Properties

Based on Annika Nerlich, a renowned researcher in the field of horticulture, soilless cultivation methods have become increasingly prominent in modern agricultural practices[19]. These methods involve employing inert organic or inorganic substrates along with nutrient solutions to support plant growth within controlled environments. In response to concerns surrounding the environmental impact and health risks associated with traditional substrates like rockwool, Nerlich's study delved into alternative materials such as wood chips, sphagnum moss, and hemp fibers. Through meticulous experimentation and analysis, Nerlich and her team aimed to evaluate the suitability of these organic substrates for lettuce cultivation, considering their physical and chemical properties and their effects on plant growth and quality. The findings of this study have significant implications for advancing sustainable and high-yield crop production methods in agriculture.

2.3.16 Solar Powered Automated Hydroponic Farming System with IoT Feedback

Based on Stella Ifeoma the solar-based hydroponic project integrates hardware and software components to enable remote monitoring and manual control[20]. The system uses relays to switch between solar power and mains AC supply based on sunlight intensity, controlled by amicrocontroller. Environmental parameters such as temperature, humidity, and nutrient solution levels are measured using sensors and uploaded online via the ESP8266 Wi-Fi module for remote monitoring. The Arduino microcontroller provides feedback to the user's phone about power source changes. Users can manually control the nutrient pump and lighting remotely through an Android mobile terminal, ensuring optimal crop growth conditions.

2.3.17 Automated Hydroponic System with Solar Powered Battery Management System

As mentioned by A. Chandra Shaker this system is designed for hydroponic plant monitoring, utilizing an Arduino as the primary controller[21]. The Arduino is interfaced with a water level sensor, DHT11 sensor, pH sensor, DC water motor, relay, and cooling fan. It continuously checks sensor data and displays it on an LCD screen. Actuators such as the cooling fan, light bulb, and water pump operate based on predefined conditions in the code. The system incorporates IoT technology using a Wi-Fi module, allowing for remote monitoring and control. Additionally, it includes a battery management system and solar panel to ensure efficient power usage.

2.3.18 Design of a smart hydroponics monitoring system using an ESP32 microcontroller

According to Anees Abu Sneineh The hydroponic monitoring system tracks daily and weekly changes in parameters like pH, EC, and nutrient levels, vital for plant growth. Rapid changes signal water and nutrient consumption by plants, necessitating daily monitoring to maintain optimal levels[22]. Stabilizing these variables enhances plant health, prevents nutrient absorption issues, and boosts productivity. For instance, pH exceeding 7.5 or EC surpassing 1800 ppm can be detrimental, leading to plant death and crop loss. This system is adaptable to various hydroponically grown plants, with programmable parameters such as pH and nutrient concentrations tailored to specific plant requirements.

2.3.19 Smart Hydroponics system

According to Ansal Sayeed In the automated hydroponics system, the addition of a solar power system aims to reduce energy costs and enhance sustainability[23]. The system's core, managed by an ESP32 microcontroller, is designed to efficiently regulate power usage, crucial for running motors and other components. A 10-watt solar panel, with a diode for current direction and a buck converter for voltage regulation, provides a reliable source of electricityTo compensate for any decrease in natural light due to solar panel installation, LED grow lights are integrated into the system. These lights ensure that plants receive adequate light for optimal growth and productivity. Moreover, to safeguard against potential component failures, especially in high-use items like motors, a motor failure detection system is implemented.

2.3.20 Indoor Hydroponic System Using IoT-Based LED

Based on Satrio Dewanto this system is made for farming using indoor hydroponic system with Artificial LED grow light [24]. Artificial led grow light uses three types of led, which is blue, red, and nff, each of which consists of ten led. Each type of led is connected to the driver so that the intensity can be adjusted according to the needs of the plants. This system has two chamber at the top and bottom, the top chamber has 8 hole on the top for seeding plant, where in each hole there is a netpot for placing rockwool and plant seeds. The lower chamber functions as water reservoir to carry out the ebb&flow irrigation system. The lower chamber functions as a water reservoir to carry out the ebb-and-flow irrigation system, ensuring a consistent supply of water and nutrients to the plants.

2.3.21 Comparison table of related journals

Table 2.1 Comparison of jurnal

No.	Author	Title	Year	Component	Method
1.	Simon Siregar Marlindia Ike Sari, Rakhmi Jauhari	Automation system hydroponic using smart solar power plant unit	2020	1. Microcontroller Atmega 328 2. LM35 as temperature sensor 3. LDR as light intensity sensor 4. pH Meter as pH sensor 5. Ultrasonic as water level sensor 6. Relay as thermoelectric 7. Relay as water pump 8. Relay as Led grow light 9. LCD as display 10. Buzzer as sound	• This prototype of automation for hydroponics system using solar power as renewable energy source is proposed. In this prototype, several parameters are measured to control the hydroponics system and solar power energy. • The parameters that are measured for control and monitoring the hydroponics system are temperature, light intensity, nutrient solution. For the solar power energy, the parameters that is measured for control and monitoring are • voltage and current from the solar panel system.
2.	Diego S. Domingues ,Hideaki W.Takahash i , Carlos A.P. Camara, Suzana L. Nixdorf	Automated system developed to control pH and concentration of nutrient solution evaluated in hydroponic lettuce production	2022	1. Conductivity Meter 2. Ph Meter 3. External Switching Circuit 4. Webcam 5. Combined Electrode Of Ph 6. Temperature Sensor 7. Conductivity Cell	• Be observed that the cultivation carried out conventionally differed from automated hydroponic cultivation only in the levels of macronutrients nitrogen, phosphorus and magnesium.

3.	Mr. Parth Varmora, Mrs.Heta Shah**, Mr. Shashank Shah**	Design and Development of Solar Powered Smart Hydroponic	2020	1. Solar Panel Unit 2. Power Supply 3. Humidifier 4. Exhaust Fan 5. Ph And Ac Transmitter 6. Heater 7. Cooling Fan 8. Light 9. Level Sensor	• An automated hydroponic system, cantered around a PLC (FX5U), controls crucial parameters like temperature, humidity, pH, and conductivity to optimize plant growth. • Supplementary components such as heaters, cooling fans, humidifiers, and exhaust fans are integrated to adjust environmental condition as needed
4.	Zikhona Buyeye, Gareth Lagerwal l1, Aidan Senzanje 1, Alistair Clulow2 and Sipho Sibanda3	Evaluation of the Resource Use Efficiencies of Small Scale Vertical Hydroponic Structures against Growing Plants in Soil	2020	1. Relay 2. Heater 3. Exhaust Fan 4. Ph Meter	• Small scale vertical hydroponic structures had higher resources use efficiencies than soil plantings. • Vertical hydroponic structures showed high agricultural productivity in term of land, water, and energy use. • Crop water productivity and energy use efficiency were significantly higher in hydroponic structures compared to soil planting.
5.	Chris Lopez	Energy Sustainable Hydroponic with Automated Reporting and Monitoring	2020	1.. Heater 2.. Cooling Fan 3. Light 4. Level Sensor 5. Dosing Pump	Developed A Nutrient Film Technique (NFT) Hydroponic system with automated functions for nutrient levels, water quality, circulation, and lighting. • The system features a user-friendly touch screen interface, allowing control of pH levels, temperature, humidity, light, and tank fill levels.

	Author	Title	Year	Component	Method
6	W. Wedashwara 1	Solar powered IoT based smart hydroponic nutrition manageme nt system using FARM	2021	1. Microcontroller Atmega 328 2. Relay module 3. LDR as light intensity sensor 4. Solar panel 5. Nutrient pump 6. Solenoid valve 7. Power supply	• The IoT system use dht11, light intensity, and rain intensity as environmental data input for the microcontroller • The increase of TDS value will turn on the solenoid valve to drain the water, and the reduced TDS value will turn on the pumps for the nutrition mix
7	Sambo P, Nicoletto C, Giro A,	Hydroponic Solutions for Soilless Production Systems Issues and Opportuniti es in a Smart Agriculture Perspective	2020	1. Conductivity Meter 2. Ph Meter 3. External Switching Circuit 4. Webcam 5. Combined Electrode Of Ph 6. Temperature Sensor 7. Conductivity Cell	• The project involves real time monitoring of solution parameters including temperature, ph, and ionic strength to optimize nutrient availability. • Investigation focus on factors such as precipitation, co-precipitation, and Complexation to understand their influence on hydroponic nutrient solutions. • Advanced analytical techniques are employed to enhance nutrient uptake efficiency and maximize plant growth in the hydroponic system

8	Muhammad Syahmi Kamarulzaman1 ,	Monitoring System of Hydroponic Using Solar Energy	2021	1. Solar Panel Unit 2. Lead Acid Battery 3. Buck Converter 4. Water Sensor 5. Temp Sensor 6. Ph Sensor 7. Light 8. Level Sensor	• The component of this project consists of solar panel, charger controller, rechargeable battery, Arduino , lcd, temperature sensor, pH sensor and water level sensor. • Solar panels are used to capture and convert the solar energy to electrical energy • electrical energy is stored in 12v battery which is controlled by charger controller to avoid overcharging.
9	Aidan Senzanje , Alistair Clulow	Evaluatin of the Resource Use Efficiencies of Small Scale Vertical Hydropon ic Structures against Growing Plants in Soil	2022	1. Relay 2. Ph Meter 3. Grow Light 4. Nutrition Pump	• Use of the vertical plane enabled the hydroponic structures to occupy a small horizontal area whilst producing more plant per unit area. • The vertical structures were able to produce more plants per unit area than the soil set up for both light treatment.
10	W Wedashwara 1*, A H Jatmika1 , AZubaidi1 and Arimbawa2	Smart solar powered hydroponi c system using internet of things and fuzzy associatin rule mining	2022	1. Light 2. Level Sensor 3. Dosing Pump 4. Glow Light 5. Voltage Regulator	• Selection of a hydroponic vertical design for the experiment, utilizing Swiss chard as the test crop. • Implementation of a randomized complete block design with factors including growing method, light provisions, and nutrient solutions concentration. • Conducting trials over two cropping seasons, with meticulous attention to factors such

					as natural sunlight versus artificial light and varying nutrient solution concentrations.

No.	Author	Title	Year	Component	Method
11	Artur Mielcarek , Karolina	Water Nutrient Management in Soilless Plant Cultivation versus Sustainability	2020	1. Mixing tank 2. Water pump 3. Power supply 4. Crop 5. Uv lamp	• under-cover soilless cultivation is an important technique of crop production. Due to the lack of contact with soil and precipitation, the root system of crops grown must be provid with water and all necessary nutrient in the form of a solution • This nutrient medium need to be fed in excess to ensure proper plant development and the expected qualitative and quantitative parameters of the crop yield

12	Alexandra Afonso , Carlos Ribeiro 1 , Maria João	Pretreated Agro-Industrial Effluents as a Source of Nutrients for Tomatoes Grown in a dual Function Hydroponic System Tomato Quality Assessment	2021	1. Conductivity Meter 2. Ph Meter 3. External Switching Circuit 4. Temperature Sensor 5. Automatic Drip Irrigation	• In a zero waste approach for the agro industrial sector, this study aim to evaluate the reuse of cheese whey wastewater pretreated by immediate one step lime precipitation followed by natural carbonation as a nutritive solution for tomato production in hydroponic systems. • Pretreated effluent diluted with groundwater and supplemented with nutrient was utilized to irrigate different hydroponic system designed to assess the influence of tomato rooting type and the feed solution level
13	D.Sarathkumar	Solar Based Hydroponics Cultivation	2022	1. Solar Panel Unit 2. Lead Acid Battery 3. Humidity Sensor 4. Ph Sensor 5. Light 6. Buzzer	• The project integrates solar-based supply and automated water flow control to enhance plant growth via soil-less hydroponic cultivation, aiming to increase efficiency and reduce reliance on traditional energy sources. • Utilizing Arduino programming, the system employs solar panels, relays, and pumps to manage water delivery to plants based on humidity levels, optimizing resource usage and crop yield. • By harnessing solar energy, the project aims to minimize electricity costs and spatial constraints associated with conventional cultivation

14	Yasir Hanif Mir	Soilless farmingAn innovative sustainable approach in agriculture	2022	1. Relay 2. Ph Meter 3. Grow Light 4. Nutrition Pump	• Soilless farming techniques, including hydroponics, aeroponics, and aquaponics, are explored as alternatives to traditional soil-based agriculture. • Among these methods, hydroponics is highlighted for its efficient nutrient delivery system, where dissolved nutrients are supplied to plants without soil and runoff. • The study also delves into the specifics of the drip irrigation system within hydroponics, emphasizing its one-time use of nutrient solutions to mitigate the risk of plant infection.
15	Annikanerlich	Soilless Cultivation Dynamically Changing Chemical Properties and Physical Conditions of Organic Substrates Influence the Plant Phenotype of Lettuce	2022	1. Light 2. Level Sensor 3. Dosing Pump 4. Glow Light	• The study compare organic substrates with rockwool in a greenhouse. • Physical properties like water retention were examined to understand how well the organic materials retained moisture compared to rockwool.

No.	Author	Title	Year	Component	Method
16	Stella Ifeoma Orakwue	Solar Powered Automat ed Hydropo nic Farming System with IoT Feedback	2022	1. Wifi module 2. Control unit 3. Power supply 4. Solar charge controller 5. Uv lamp	• The solar-based hydroponic project integrates hardware and software components to enable remote monitoring and manual control. The system uses relays to switch between solar power and mains AC supply based on sunlight intensity, controlled by a microcontroller. • Environmental parameters such as temperature, humidity, and nutrient solution levels are measured using sensors and uploaded online via the ESP8266 Wi-Fi module
17	A. Chandra Shaker, L. Sai Srivalli, K. Sharanya, D. Akhila	Automated Hydroponic System with Solar Powered Battery Manage System	2020	1. Solar Panel 2. Ph Meter 3. Solar Charger 4. Temperature Sensor 5. Arduino 6. Dht11 7. Water Sensor	• The Arduino is interfaced with a water level sensor, DHT11 sensor, pH sensor, DC water motor ,relay. It continuously checks sensor data and displays it on an lcd screen. Actuators such as the cooling fan, light bulb, and water pump • This system incorporates IoT technology using a Wi-Fi module, allowing for remote monitoring and control.

18	Anees Abu Sneineh	Design of a smart hydroponic monitoring system using an ESP32 microcontroller and the Internet of Thing	2023	1. Solar Panel Unit 2. Lead Acid Battery 3. Humidity Sensor 4. Ph Sensor 5. Tds Sensor 6. Esp32 7. Water Pump	• Rapid changes signal water and nutrient consumption by plants, necessitating daily monitoring to maintain optimal levels.Stabilizing these variables enhances plant health, prevents nutrient absorption issues, and boosts productivity. • For instance, pH exceeding 7.5 or EC surpassing 1800 ppm can be detrimental, leading to plant death and crop loss.This system is adaptable to various hydroponically grown plants, with programmable parameters such as pH and nutrient concentrations tailored to specific plant requirements

19	Adhila Unas1, Amrutha Dilip2, Ansal Sayeed	Smart Hydroponics system	2022	1. Esp32 2. Ph Meter 3. Grow Light 4. Nutrition Pump 5. Water Pump 6. Solar System 7. Ec Sensor	• The system's core, managed by an ESP32 microcontroller, is designed to efficiently regulate power usage, crucial for running motors and other components. • A 10-watt solar panel, with a diode for current direction and a buck converter for voltage regulation, provides a reliable source of electricity • To compensate for any decrease in natural light due to solar panel installation, LED grow lights are integrated into the system. These lights ensure that plants receive adequate light for optimal growth and productivity.
20	Ivan Alexander*, Satrio Dewanto	Indoor Hydroponic System Using IoT-Based LED	2022	1. Esp32 2. Humidity Sensor 3. Relay 4. Led Driver 5. Glow Light 6. Voltage Regulator 7. Dc Fan	• Artificial LED Grow Light uses 3 types of led, blue, red, and nff, each of which consists of 10leds. • Each type of led is connected to the driver so that the intensity can be adjusted according to the needs of the plants.

2.4 Plants suggestion

2.4.1 Lettuce

Lettuce is a cold season crop needing growing temperatures ranging from 7 to 24 degree Celsius, with an average of 18 degree Celsius per second and pH value requirement between 6.0 to 6.2(Lorenz & Maynard, 1988). (Lorenz & Maynard, 1988). The growing of lettuce using soilless methods has lately gained popularity in South Africa as a result of improvements in both quality and yield (Maboko & Du Plooy, 2008).

2.4.2 Spinach

When growing spinach in aquaponics, it is important to keep in mind that excessive sun exposure might cause the spinach to bolt and develop a bitter flavour. So, as the weather becomes hot, make sure to keep it shady (Andrew Vergeer, 2022). The spinach's pH requirement is around 6.0 to 7.0 while the temperature range from 45 degrees to 75 degrees Fahrenheit.

2.4.3 Basil

Growing hydroponic basil is popular among commercial producers, home gardeners, and educators because it develops fast in the system and has a high yield (Ferrarezi & Bailey, 2019). This plant has a rapid growth rate, with the potential to sprout within five days and reach harvestability within 25 days. When harvesting the basil, make sure that wouldn't take well over a 1/3 of the plant at a time. The pH value of basil requirement between 5.5 to 6.5 while the temperature 65 to 85 Fahrenheit. This will help the plant continue to thrive. Since basil thrives in warm climates, it is important to grow it in a location where it receives between 6 and 8 hours of sunlight each day (Andrew Vergeer, 2022) .

2.4.4 Plants suggestion table

Table 2.2 Plant suggestion table

NO	REFERENCES	MATERIALS/ OBJECTIVES	METHOD	RESULT
1	Tabaglio, V., Boselli, R., Fiorini, A., Ganimede, C., Beccari, P., Santelli, S., & Nervo, G. (2020). Reducing nitrate accumulation and fertilizer use in lettuces with modified intermittent Nutrient Film Technique (NFT) system. *Agronomy*, *10*(8), 1208.	Testing a nutrient film technique (NFT) for soilless lettuce production in which plants are cultivated peat block in trays and fed an erratic flow of nutrient water	a. Lettuce grown with the NFT method is now being offered in a more appealing manner to customers. b. Three different varieties of lettuce (Batavia, Romana, and Lollo, all of which are cv. longifolia). c. Approximately 200 g of the package's included inside its 400 g weight, which is equal to roughly two portions of a mixed salad.	Soilless lettuce may be grown using an innovative method called intermittent NFT, in which the last stage of growth is reduced in fertilizer rate to maximise output and concentration of nitrates in the leaves.
2	Rathod, A. D., Murukar, R. P.,	The hydroponic structure will be	Research on "Nutrient Film	In the green hydroponic

	& Gupta, S. V. (2020). Modification and Performance Evaluation of Hydroponics Structure with Nutrient Film Technique for Spinach. *Int. J. Curr. Microbiol. App. Sci*, *9*(1), 2544-2555.	used to monitor spinach's development and quality from February to April of 2019.	Technique for Spinach" was carried out in 2018/19. For the experimental research, this chapter provides information on how to design an experiment, how to collect data, how to analyse the data, and how the experiment was conducted.	framework, the yield was found to be at its highest. The open field yielded two times less than the hydroponic structure of green, white, and uv-polyethylene.
3	Walters, K. J., & Currey, C. J. (2015). Hydroponics greenhouse basil production: Comparing systems and cultivars. *HortTechnology*, *25*(5), 645-650.	quantifying and describing the growth characteristics of two hydroponic basil cultivars.	a. Commercial hydroponic application was deemed impracticable for the cultivars we evaluated because to their tiny leaf size, excessive compact growth, short stem length, and poor output. b. Basil seeds from 35 different cultivars from numerous species were collected from a variety of places.	Although cultivars should be chosen based on taste, habit, and yield when selecting hydroponic basil, growers should also consider operational preferences when selecting a production method. Variations in production

4	Grigas, A., Kemzūraitė, A., Steponavičius, D., Steponavičienė, A., & Domeika, R. (2020). Impact of Slope of Growing Tray on Productivity of Wheat Green Fodder by a Nutrient Film Technique System. *Water*, *12*(11), 3009.	The production and quality of wheat fodder may be affected by the slope of the hydroponic growth tray used throughout the nutrient film technique.	a. Hydroponic wheats fodder production may be evaluated utilising a nutrient film method hydroponic fodder growing equipment. b. There have been 1.5 percent (0.86) increases in the growth trays' slope angle from 2.0 percent (1.15) to 8.0 percent (4.57). c. Indoor lighting (fluorescent lamps) and light emitting diode illumination were both employed in this study to illuminate wheat sprouts.	The idea that employing macros and micronutrients in the nutrient solution does not substantially alter the productions of wheat fodder cultivated hydroponically for seven days

2.5 Water quality

The nutrients and oxygen that plants need to survive are carried to them in the form of oxygen and nutrients by water. For appropriate management of an hydroponic, including how to operate a business that is successful and sustainable as well as how to extract the most of the plantsand bacteria, it is essential to have a fundamental understanding of water chemistry (Masabni & Sink, n.d. 2021).

2.6 pH level

The ph of the water utilised in hydroponics systems is an important indication of its quality. pH, which stands for power of hydrogen, is a term used to define the concentration of hydrogen ion in a solution, which may be expressed as a number. An acidic environment is indicated by the pH scale's zero-to-seven range, seven indicates a neutral environment, and seven to 14 indicates a basic or alkaline environment (Gogreenaquaponics.com. Maintaining a pH level that is ideal for both plants and crops is critical. In the case of tilapia, for example, a pH range of 5.0 to 10.0 is required. Plants from the other hand, thrive at pH levels lower than 6.5. When the pH falls below 6 and higher 7.5, nitrifying bacteria stop generating nitrogen. Fish, plants, and nitrifying bacteria are the three main components of an aquaponics system. For all three elements, the ideal pH range is between 6 and 7.All parts of the system will work well as long as the pH is kept between 6.4 to 7.5.

Summary

This literature review chapter compares nearly 20 previous projects focused on sustainable and space-efficient agricultural practices. It highlights the similarities and differences among these initiatives, particularly their use of various sensors and technologies. My proposed project distinguishes itself by integrating solar power need to eliminate the need for power cable, thereby enhancing sustainability and reducing reliance on conventional energy sources.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will provide precise and detailed descriptions and justifications of component, theoretical approaches, project design, and method. As a result, the flow chart's progress will be depicted to provide a clear and better explanation. The material employed in the project, as well as procedural information on the circuit connection setup method, will be discussed.

3.2 Project Work Flow

The project process is crucial to a good project conclusion, as shown in the diagram below. A typical project approach began with meticulous planning and progressed to extensive research. To obtain as much information as possible to help in the design and comprehension of the project, a range of tactics and tools can be employed. Journal research and studies published in engineering books, for example, might be used to help develop a high quality or desired project. The next stage is to undertake a thorough examination of the desired parameter and aspect, as well as its benefits and drawbacks.

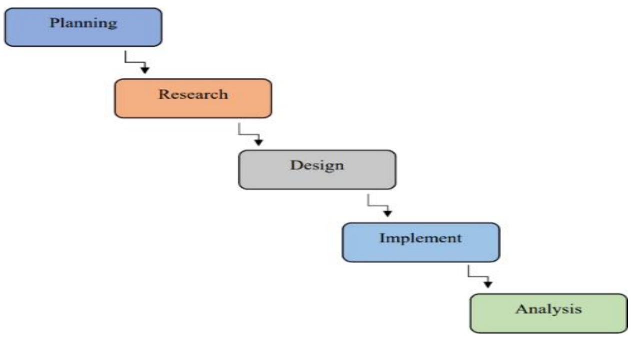

Figure 3. 1 Project work flow

3.3 Planning

Projects planning is a type of project management that comprises using schedules like Gantt charts to plan and track project progress. The goal of the project is to build a low-cost solar powered soilless cultivation system.

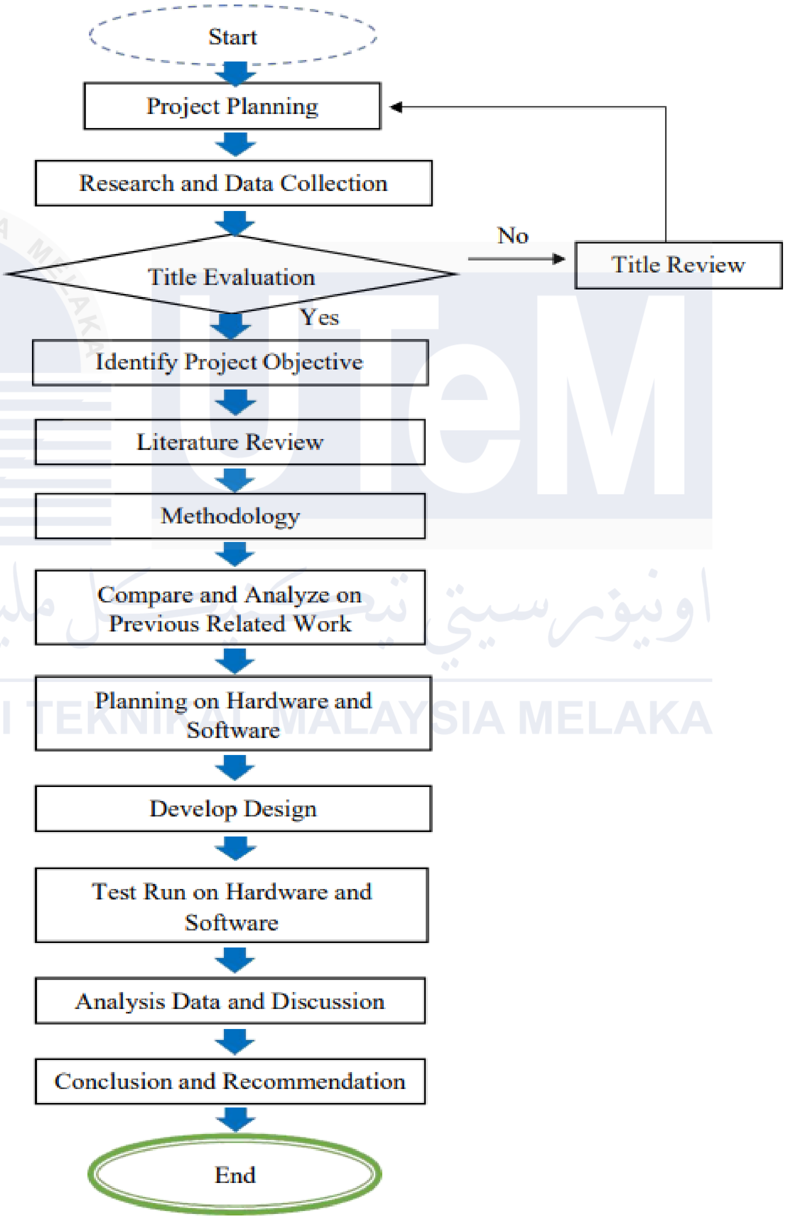

Figure 3. 2 Planning flow

3.3.1 Block diagram

The small-scale, solar-powered hydroponic system operates through a series of inputs and outputs to maintain optimal growing conditions for plants. Inputs include a solar panel that captures and converts solar energy into electrical power and various sensors that monitor key parameters: a temperature sensor for ambient temperature, a humidity sensor for moisture levels, a pH sensor for the nutrient solution, a light sensor for ambient light intensity, and an LDR for real-time light detection. The ESP32 microcontroller processes the data from these sensors to evaluate the growing conditions. Based on this data, the system generates automated responses such as nutrient dosing, irrigation control, pH adjustment, and grow light activation to ensure optimal plant growth. Additionally, the system sends notifications to the user via an app or display to inform them of any necessary adjustments. This integration of inputs and outputs makes the system efficient, sustainable, and user-friendly.

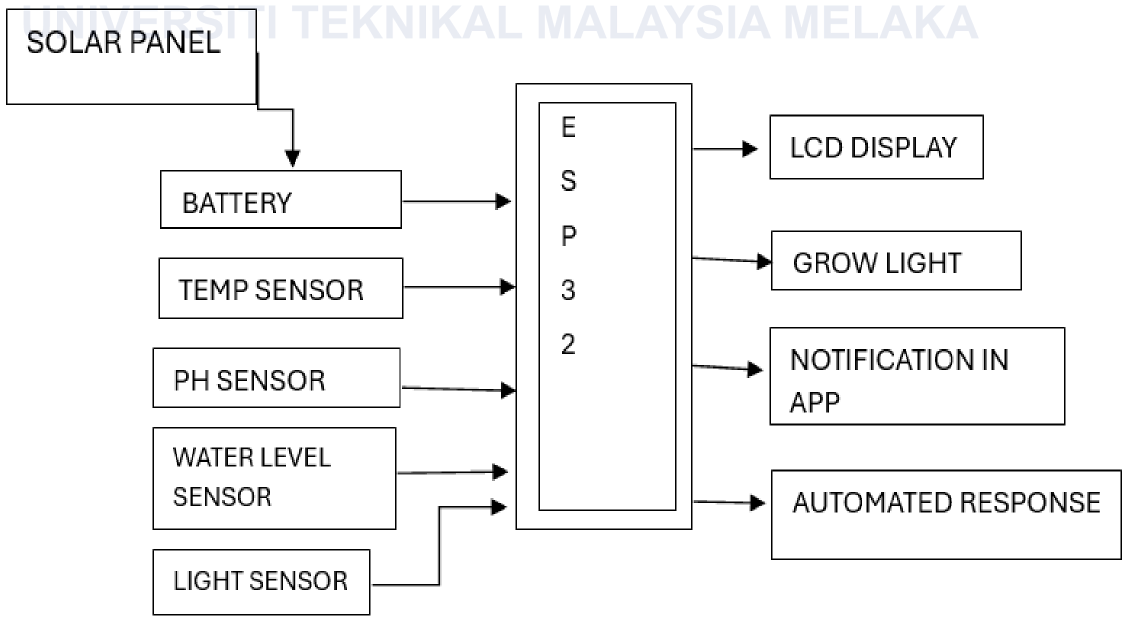

Figure 3. 3 Block diagram of hydroponic system

3.3.2 Flow chart

The flowchart represents the workflow of the IoT-based Solar Powered Soilless Cultivation System. It begins with connecting the IoT application to the ESP32 microcontroller, which establishes communication with the system. The system then uses various sensors to monitor and maintain optimal conditions for plant growth.

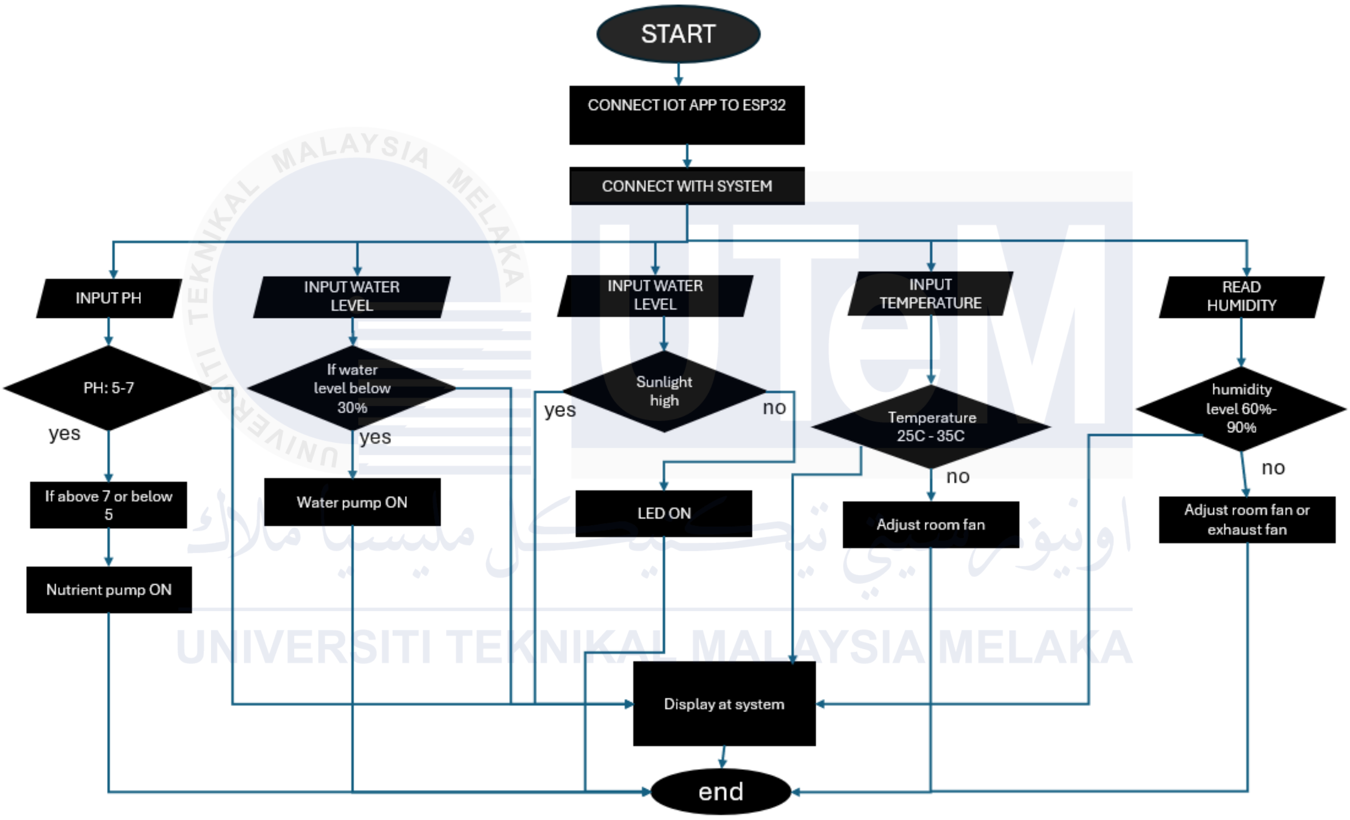

Figure 3. 4 Flowchat of proposed system

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3.3.3 Flowchart explanation

The pH sensor measures the pH level of the water in the tank. For the hydroponic the optimal pH should be around 5-7 at the best. So if the pH value falls outside the optimal range of 5 to 7, the system activates the nutrient pump to adjust it accordingly. Same goes to the water level sensor which ensures the water level remains adequate on the tank. If it drops below 30%, the water pump is automatically turned on to refill the reservoir. The system also monitors sunlight intensity. If sunlight levels are sufficient, no additional action is taken. However, if sunlight is low or absent, the LDR sensor will detect it and turns on an LED light to provide artificial lighting for the plants.

The temperature sensor monitors the temperature. If the temperature deviates from the ideal range of 25°C to 35°C, the system will update on the IOT app,So the user must manually adjust the room fan to regulate the temperature.The humidity sensor ensures that humidity stays within the range of 60% to 90%. If the humidity level falls outside this range, the system suggests using the room fan or exhaust fan to correct it, leaving the adjustment up to the user.

Finally, all sensor readings and system statuses are displayed on the interface, providing the user with real-time updates for effective monitoring and manual intervention where necessary. This combination of automation and user control ensures an efficient and flexible system for soilless cultivation.

3.4 Hardware explanation

The hardware components selected for this project are standard and widely available, ensuring accessibility and cost-effectiveness. These components were chosen based on their reliability, compatibility, and ability to meet the system's requirements. Each hardware element plays a vital role in the implementation of the smart hanger system, contributing to its functionality and efficiency. Additionally, the hardware is designed to integrate seamlessly with the IoT framework, enhancing the system's overall performance. This ensures that the smart hanger system is both user-friendly and adaptable to various environments. The details of these components and their roles will be discussed in the following subtopics.

3.4.1 DHT22 sensor (temperature and humidity sensor)

The DHT22 sensor, commonly used in solar-powered hydroponic systems, features four pins with distinct functions. The VCC pin connects to the power supply, typically requiring either 3.3 volts (V) or 5 volts (V) depending on the model. It's crucial to adhere to the specified voltage range to avoid damaging the sensor. The Data Out pin serves as the signal output, transmitting temperature and humidity data using a single-wire protocol to a microcontroller or compatible device. The Not Connected (NC) pin is unused in standard operations and can be left unconnected. Finally, the Ground (GND) pin completes the circuit by connecting to the system's ground or negative power supply terminal. When interfacing with a microcontroller, ensure proper pin connections to VCC, Data Out, and Ground to enable accurate data transmission and sensor functionality.

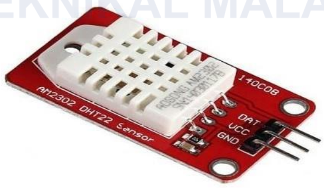


Figure 3. 5 DHT22 sensor

3.4.2 Light dependent resistor

A light dependent resistor LDR, also known as a photo resistor or photocell, variable resistor that is controlled by light . Its resistance varies depending on the amount of light falling on it. The wavelength of light incident on them affects their sensitivity. It’s constructed in such a way that the maximum feasible contact area between two metal films is achieved. The principle of Photo Conductivity is used in LDR. The electron in the valence band is stimulated to the conduction band when photons strike the substance. As a result, protons must have an energy large than the semiconductor material's band gap. The resistance of LDR reduces when light strikes on it. When an LDR is kept in the dark, its resistance is high, which causes the transistor to switch on and the led to light up. LDR sensors are light-sensitive and non-linear. LDR sensors are non- electrical and do not produce any energy. When a steady voltage is provided, the light intensity and current both grow. The graph below depicts the resistance vs. illumination curve for a certain light-dependent resistor.

Figure 3. 6 LDR sensor

3.4.3 ESP32 wifi bluetooth module

The ESP32 WROOM-32 module, a versatile microcontroller commonly used in projects involving soilless cultivation, features several critical pins essential for system integration. The VCC pin connects to the power supply's positive terminal, providing the necessary voltage (typically 3.3 volts) to operate the module, while the GND pin connects to the negative terminal, completing the circuit. Additionally, the module offers a range of GPIO pins that can be configured for various functions such as digital inputs or outputs, analog inputs, and specialized functionalities. These GPIO pins are pivotal for interfacing with sensors, actuators, and external devices within the soilless cultivation system, enabling data acquisition, control, and communication processes essential for system functionality .

Figure 3. 7 ESP32 microcontroller

3.4.4 DC water pump 385 DC 12V pneumatic water pump motor

The DC water pump 385, designed for operation at 12 volts DC, serves as a vital component in solar-powered hydroponic or soilless cultivation systems for efficient water circulation. When integrating this pump into such systems, it's crucial to ensure a stable power supply within the specified voltage range. The positive (+ve) terminal of the pump connects to the positive terminal of the power supply, while the negative terminal completes the circuit by connecting to the negative terminal of the power supply. Additionally, depending on the pump's model or features, it may have control pins for functionalities like speed or direction control, allowing for precise management of water flow rates. Considering the pump's current rating is also important to prevent overloading the power supply. Properly connecting water inlet and outlet ports with tubing or hoses ensures effective water distribution within the hydroponic or soilless cultivation setup. Strategic mounting and placement of the pump optimize water circulation and contribute to the overall efficiency of the system.

Figure 3. 8 Water pump

3.4.5 3W 12V 250MA Polycrystalline solar panel

The 3W 12V 250mA polycrystalline solar panel is a crucial element in solar-powered setups, including those tailored for hydroponic or soilless cultivation systems. Its specifications, such as the 3-watt power output, 12-volt voltage rating, and 250mA current capacity, are instrumental in determining its performance and compatibility with connected devices.

Utilizing polycrystalline technology, this panel offers a cost-effective yet efficient means of harnessing solar energy. When integrating the solar panel into a system, proper wiring and connection to a charge controller are essential to ensure optimal energy conversion, prevent overcharging, and maximize the panel's output for powering the system's components effectively.

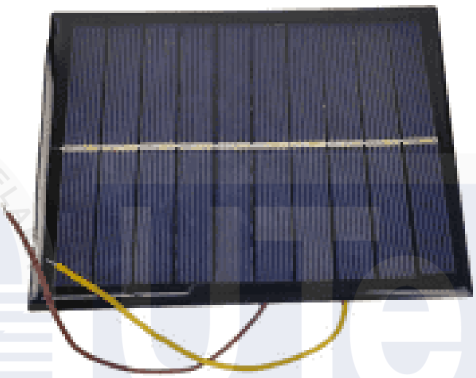


Figure 3. 9 12v Solar panel

3.4.6 Relay 4 Channel 5V Opto

The 4 Channel relay module with opto coupler is often used to control various appliance and equipment with large current such as motor, DC and AC Load, lights and more. Standard interface that can be controlled directly by ESP32 microcontroller, arduino uno, raspberry pi and etc.

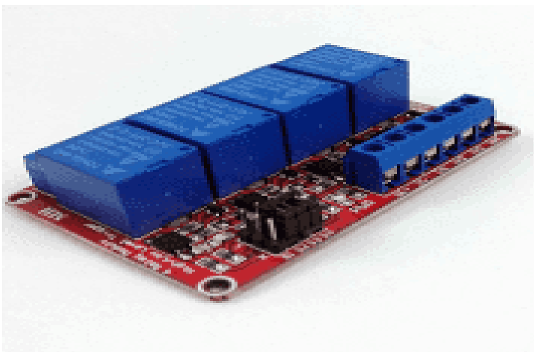


Figure 3. 10 4channel relay module

3.4.7 USB LED grow light

LED grow lights are indispensable components in indoor gardening systems, particularly in hydroponic and soilless cultivation setups, as they provide the necessary artificial light for plant growth. These lights are designed to emit specific wavelengths of light essential for photosynthesis, including blue and red spectra for different growth stages like vegetative growth and flowering. One of their key advantages is energy efficiency, as they consume minimal power and produce little heat compared to traditional lighting sources, reducing energy costs and the risk of heat damage to plants. Durability and long lifespan are other notable features, with quality LED grow lights lasting tens of thousands of hours and requiring minimal maintenance. They often include cooling systems such as fans or heat sinks to manage heat dissipation and maintain optimal operating conditions. Proper mounting and positioning of LED grow lights ensure even light distribution and maximum coverage for healthy plant growth throughout the cultivation cycle.

Figure 3. 11 LED grow light

3.4.8 12V rechargeable sealed lead acid

Sealed lead acid battery or gel cell is lead acid battery that has the sulfuric acid electrolyte coagulated so it cannot spill out. They are partially sealed, but have vents in case gases are accidentally released for example by overcharging. They can be used for smaller application where they are turned up side down. They are expensive than normal lead acid batteries, but they are also more safer. Maintenance-free, replenishment free, and reusable when used in a safe environment. A long service life. High safety, special low impedance, and strong charge acceptance. Excellent tightness (no leakage of liquid or acid gas). Extremely low self-discharge, making the product highly reliable. Installable in any direction, facilitating safe transportation.

Figure 3. 12 12v rechargeable battery

3.4.9 Charge solar controller

Solar charge controllers are integral components in solar-powered systems, including those tailored for hydroponic or soilless cultivation setups. Their primary function is to regulate the charging process of batteries or storage devices using solar energy efficiently. These controllers play a pivotal role in maintaining optimal battery health and prolonging their lifespan by preventing overcharging and deep discharging. They achieve this through voltage and current regulation, ensuring that the energy harvested from solar panels matches the charging requirements of the batteries. Additionally, solar charge controllers offer features like temperature compensation, low-voltage disconnect (LVD), and load control capabilities for managing DC loads directly from the controller. They also provide monitoring and display functionalities, offering real-time data on system performance, battery status, and charging parameters, enabling users to track and optimize their solar-powered systems effectively.

Figure 3. 13 Solar charger controller

3.4.10 Current sensor acs712

The ACS712 current sensor is a critical component used in electrical systems, including those integrated into hydroponic or soilless cultivation setups, to provide accurate current measurements for monitoring and control purposes. This sensor utilizes Hall-effect technology to detect magnetic fields generated by current-carrying conductors, converting these fields into a proportional voltage output that can be interpreted by microcontrollers or monitoring systems. With variants available in different current ranges and sensitivities, such as 5A, 20A, or 30A models, the ACS712 sensor offers flexibility for various application needs. Its non-invasive installation allows for easy attachment to conductors without circuit interruption, making it suitable for retrofitting into existing systems.Its applications in hydroponic or soilless cultivation systems include monitoring and controlling the power consumption of pumps, lights, fans, and other electrical components, facilitating energy usage tracking and implementation of energy-efficient strategies for optimal system performance.

3.5 Software implementation

3.5.1 Code development using Arduino

Arduino ide is a text editor that is created in the C and C++ programming language. It's a general free open-source software that's simple to programme and compile. The basic feature makes it possible for those with no prior programming experience to develop code. The Arduino IDE is frequently used to write and modify code for various Arduino micro controller boards. The Arduino IDE is required for writing and importing code to the Arduino Uno in the project.

Voltage and current reading code

```
for(int i = 0; i < 1000; i++) {
        Vout = (Vout + (resADC * analogRead(crntsenpin)));
        delay(1);
      }
    // Get Vout in mv
        Vout = Vout /1000;

      // Convert Vout into Current using Scale Factor
      Current = (Vout - zeroPoint)/ scale_factor;
      Serial.print("Vout:");Serial.print(Vout);Serial.print("V");
      Serial.print(" Current:");Serial.print(Current);Serial.print("A");
      Serial.print(" ");
lcd.home();
lcd.setCursor(0, 2);
lcd.print("Solar Voltage:");
lcd.setCursor(14, 2);
lcd.print((Vout),1);
lcd.print("V");
```

Figure 3. 14 Voltage and current reading code

This section of the program is designed to measure and analyze the voltage and current generated by the solar panel, which is essential for monitoring the efficiency and functionality of the system. The voltage (Vout) is calculated by sampling the analog input from the current sensor (connected to crntsenpin) 1000 times in a loop. This sampling ensures accuracy by reducing noise and variations in the raw readings. The analog readings are converted into voltage using the resolution and reference voltage of the analog-to-digital converter (ADC). The average voltage is then computed by dividing the accumulated value by the total number of samples.

The calculated voltage is further used to determine the current output of the solar panel by subtracting the zero-point offset (representing the baseline sensor value) and dividing the result by the scale factor specific to the ACS712 5A sensor. The scale factor translates the voltage into an accurate current value in amperes. These voltage and current values are critical in assessing the power generation of the solar panel, which can be calculated using the formula $P=V\times IP = V$, where represents power in watts. The data is displayed on the LCD screen in real time, with the solar voltage prominently shown in a user-friendly format.

<u>Water pump activation code</u>

```
if(wlvl>40) //water still full
{
  digitalWrite(waterpumppin,HIGH);

 }
else if(wlvl<10)//water below half
{
  digitalWrite(waterpumppin,LOW); //turn on pump
```

Figure 3. 15 Water pump activation code

This section of the code is responsible for monitoring the water level in the system and automatically controlling the water pump based on predefined thresholds. The wlvl variable represents the water level percentage, which is derived from the analog input of the water level sensor.

If the water level is greater than 40% (wlvl > 40), it indicates that the water level is sufficient, and the water pump is turned off by setting its pin to HIGH. Conversely, if the water level drops below 10% (wlvl < 10), it signifies a critical water shortage, and the water pump is activated by setting its pin to LOW. This ensures a continuous supply of water to maintain optimal conditions for plant growth, automating the irrigation process efficiently.

<u>PH pump activation code</u>

```
if(phValue<5) //acidic
{
  digitalWrite(phpumppin,LOW);
  } //turn on pump ph chemical
else if(phValue>5) //not acidic
{

  digitalWrite(phpumppin,HIGH);
} //turn off pump ph chemical
```

Figure 3. 16 PH pump activation code

This portion of the code ensures the pH level of the nutrient solution remains within the optimal range of 4.5 to 7.0, which is essential for plant growth and nutrient absorption. The logic checks the phValue obtained from the pH sensor. If the pH value is below 4.5, indicating the solution is too acidic, or above 7.0, indicating the solution is too alkaline, the pH pump is activated by setting phpumppin to LOW. This triggers the pump to add pH-balancing chemicals to bring the solution back to the desired range.

Conversely, if the pH value falls within the optimal range of 4.5 to 7.0, the pH pump is turned off by setting phpumppin to HIGH, preventing unnecessary operation of the pump. This logic helps conserve energy and ensures the system functions efficiently while maintaining ideal growing conditions for the plants.

LED grow light ON/OFF code

```
if(LDR_Vp==LOW) //sunny day
{
  digitalWrite(growledpin,HIGH); //turn off LED grow light

  lcd.print("HIGH");
  lightstat="HIGH";
}
else if(LDR_Vp==HIGH) //night @ no light
 {
  lcd.print("LOW ");
  digitalWrite(growledpin,LOW);//turn on LED grow light

  lightstat="LOW";
  }
```


Figure 3. 17 LED grow light ON/OFFcode

This section of the code manages the operation of the LED grow light based on light intensity detected by the Light Dependent Resistor (LDR). The LDR_Vp variable captures the LDR's digital output, where LOW indicates sufficient natural light (sunny conditions), and HIGH indicates low or no sunlight (such as during nighttime or cloudy weather). When the LDR detects enough sunlight (LDR_Vp == LOW), the LED grow light is turned off by setting the growledpin to HIGH. This reduces unnecessary power consumption. Additionally, the LCD displays "HIGH," and the variable lightstat is updated to reflect the presence of natural light. Conversely, when the LDR detects low light (LDR_Vp == HIGH), the grow light is activated by setting the growledpin to LOW. The LCD displays "LOW," and the lightstat variable indicates that artificial light is being used. This automated control ensures plants receive adequate lighting for optimal growth while conserving energy by leveraging natural sunlight during the day.

Temperature and humidity reading code

```
Humidity = dht.readHumidity();
// Read temperature as Celsius (the default)

Temperature = dht.readTemperature();

// Check if any reads failed and exit early (to try again).
if (isnan(Humidity) || isnan(Temperature) ) {
  Serial.println(F("Failed to read from DHT sensor!"));

}
else {
  Serial.print(F("Humidity: "));
Serial.print(Humidity);
Serial.print(F("%  Temperature: "));
Serial.print(Temperature);
Serial.print(F("°C "));
lcd.setCursor(0, 0);
lcd.print("Humid:");
lcd.setCursor(6, 0);
lcd.print(Humidity,0);
lcd.print("%");
lcd.setCursor(0, 1);
lcd.print("Temp:");
lcd.setCursor(5, 1);
lcd.print(Temperature,1);
lcd.print("C");
```

Figure 3. 18 DHT22 reading code

This segment of the code is responsible for reading and displaying temperature and humidity values using the DHT22 sensor. The dht.readHumidity() and dht.readTemperature() functions retrieve the current humidity and temperature data, respectively. If the readings fail—detected using the isnan() function—the code outputs an error message to the serial monitor: "Failed to read from DHT sensor!" This ensures error handling in case of sensor malfunction or communication failure.

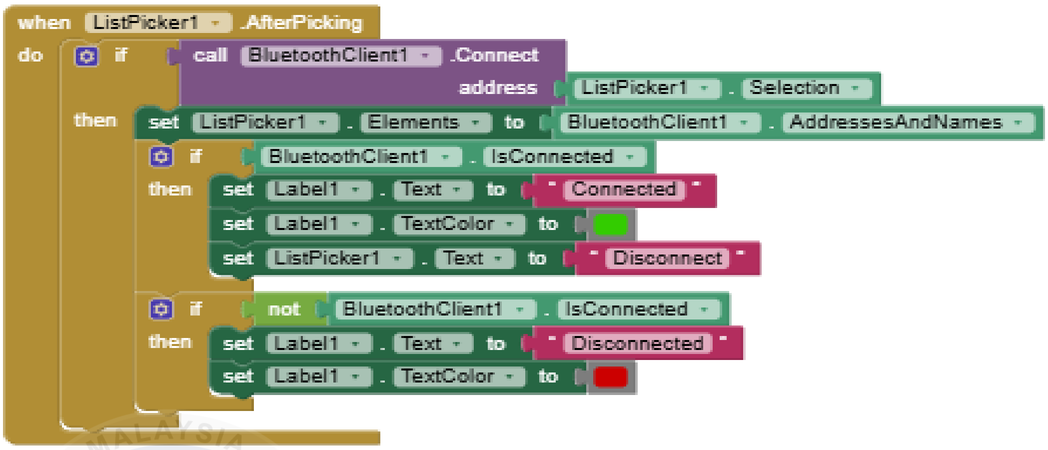
If the readings are successful, the data is processed and displayed both on the serial monitor and an LCD screen. The humidity value is printed to the LCD with the label "Humid:" followed by the percentage sign (%), while the temperature value is displayed with the label "Temp:" followed by degrees Celsius (°C). The use of the lcd.setCursor() function ensures that the data is neatly arranged on the LCD screen, with humidity values on the first row and temperature values on the second row. This section enables real-time monitoring of environmental conditions, which are crucial for maintaining optimal conditions for plant growth in a soilless cultivation system.

3.5.2 Software (MIT APP INVENTOR)

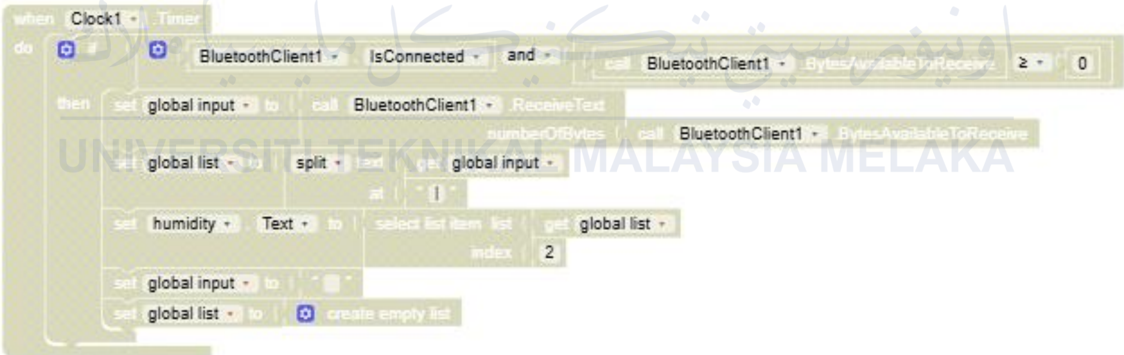
The MIT App Inventor application serves as an intuitive interface for real-time monitoring and control of the soilless cultivation system. Utilizing Bluetooth communication, the app bridges the gap between the system and the user, enabling seamless data exchange. Through its user-friendly design, the application provides critical insights into key parameters, such as temperature, humidity, water level, pH, light levels, voltage, and current, ensuring that users can monitor and manage the system with ease and efficiency.

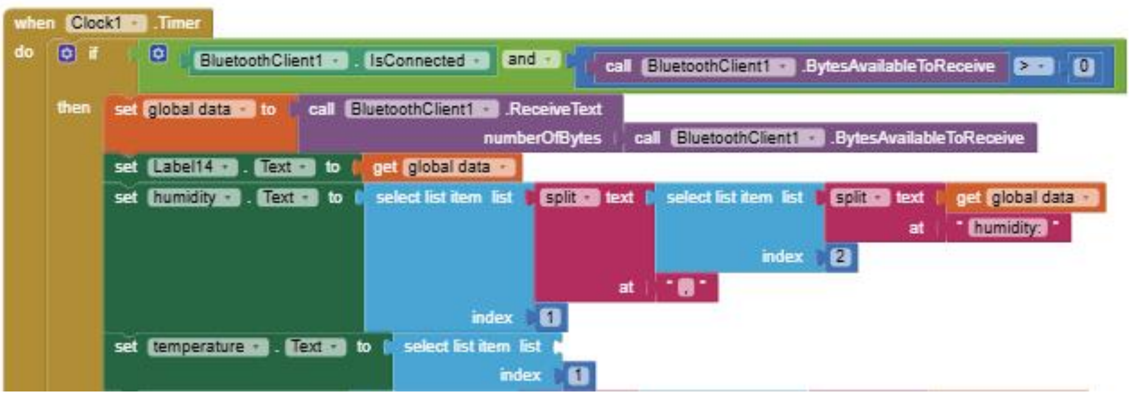
The MIT App Inventor blocks are designed to facilitate Bluetooth communication and real-time data monitoring for the soilless cultivation system. The global variables global data and global list are used to store and process incoming data received from the connected Bluetooth device. The ListPicker blocks manage Bluetooth connectivity, allowing users to select and connect to available devices.


when ListPicker1 .BeforePicking
do set ListPicker1 . Elements to BluetoothClient1 . AddressesAndNames


when ListPicker1 .AfterPicking
do if call BluetoothClient1 .Connect
address ListPicker1 . Selection
then set ListPicker1 . Elements to BluetoothClient1 . AddressesAndNames
if BluetoothClient1 . IsConnected
then set Label1 . Text to " Connected "
set Label1 . TextColor to
set ListPicker1 . Text to " Disconnect "
if not BluetoothClient1 . IsConnected
then set Label1 . Text to " Disconnected "
set Label1 . TextColor to


when ListPicker1 .TouchUp
do if compare texts ListPicker1 . Text = " Disconnected "
then call BluetoothClient1 .Disconnect
set ListPicker1 . Text to " Connect "


when Clock1 .Timer
do if BluetoothClient1 . IsConnected and call BluetoothClient1 .BytesAvailableToReceive ≥ 0
then set global input to call BluetoothClient1 .ReceiveText
numberOfBytes call BluetoothClient1 .BytesAvailableToReceive
set global list to split text get global input
at " | "
set humidity . Text to select list item list get global list
index 2
set global input to " "
set global list to create empty list


when Clock1 .Timer
do if BluetoothClient1 . IsConnected and call BluetoothClient1 .BytesAvailableToReceive > 0
then set global data to call BluetoothClient1 .ReceiveText
numberOfBytes call BluetoothClient1 .BytesAvailableToReceive
set Label14 . Text to get global data
set humidity . Text to select list item list split text select list item list split text get global data
at " humidity: "
index 2
at " "
index 1
set temperature . Text to select list item list
index 1

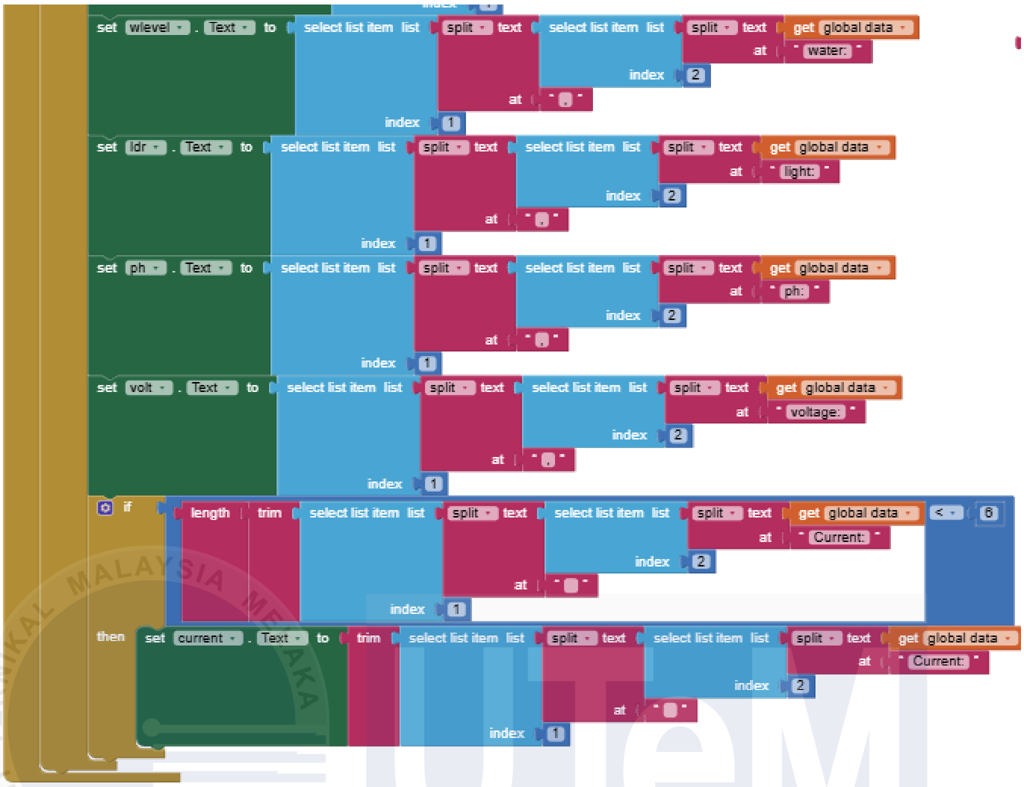


Figure 3. 19 MIT app blocks

The blocks in this system are designed to process and display real-time data from the soilless cultivation system using Bluetooth communication. The system continuously monitors environmental and operational parameters such as temperature, humidity, pH levels, water levels, voltage, and current. It collects this data through sensors integrated into the cultivation system, which are connected to an ESP32 microcontroller. The microcontroller processes the data and transmits it via Bluetooth.

The List Picker blocks manage the connection between the system and the monitoring device, ensuring seamless communication. Once connected, the Clock1.Timer block periodically fetches sensor readings through the Receive Text function. The data is then parsed and assigned to specific variables corresponding to each parameter. This ensures that critical metrics such as pH levels or water availability are updated in real-time.

The parsed data is continuously processed and made available for display, helping users monitor the system's performance. This functionality ensures the system operates efficiently by providing continuous feedback, such as activating pumps or lights based on specific conditions detected by the sensors. This real-time functionality ensures optimal growth conditions are maintained at all times.

3.6 Mit App Interface

The uploaded interface screenshot showcases the mobile application developed using MIT App Inventor. This app is designed to display real-time data from the soilless cultivation system, including readings from various sensors such as temperature, humidity, pH, water levels, and light intensity. The interface provides a simple and user-friendly way to monitor the system's performance and environment status directly from a mobile device.

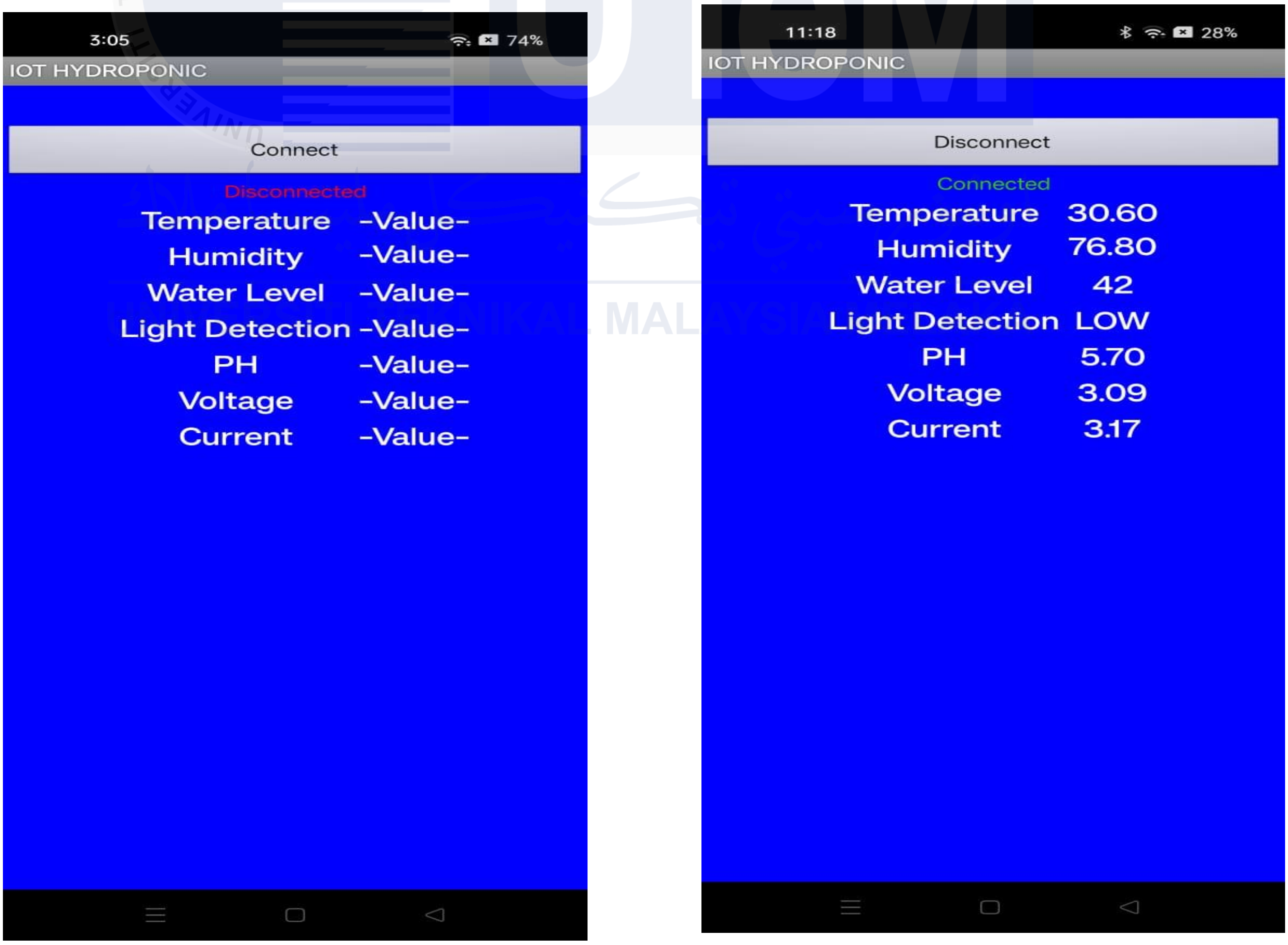


Figure 3. 20 MIT app interface on phone

3.7 Circuit design

The circuit design of the solar powered soilless cultivation system integrates various components to monitor and control key parameters such as temperature, humidity, pH levels, and water levels. The system is powered by a solar panel, which converts sunlight into electrical energy stored in a rechargeable battery to ensure continuous power supply even during periods of low sunlight. This energy is regulated to provide a stable output to all system components. At the system is the ESP32 microcontroller, which processes data from the sensors and controls the actuators based on predefined conditions.Several sensors are connected to the ESP32 for real-time data collection. The DHT22 sensor measures both temperature and humidity and is connected to the microcontroller's digital input pins.

This sensor provides crucial data that the microcontroller uses to maintain optimal growing conditions. The pH sensor, connected to an analog input pin, monitors the nutrient solution's acidity or alkalinity, enabling the microcontroller to trigger the nutrient supply if adjustments are needed. Two water level sensors are employed to monitor the nutrient solution level, with one sensor placed at a high level and the other at a low level. These sensors are connected to digital input pins, allowing the microcontroller to activate the water pump if the water level drops below or rises above the specified thresholds.The system includes several actuators controlled by the ESP32 through relay modules.

The water pump is activated when the water level is low, replenishing the nutrient solution as needed. Artificial lights, such as LED grow lights, are turned off if the temperature exceeds 30°C to prevent overheating. Humidifiers and dehumidifiers are also controlled by the microcontroller, which activates the appropriate device based on humidity readings to maintain optimal levels.

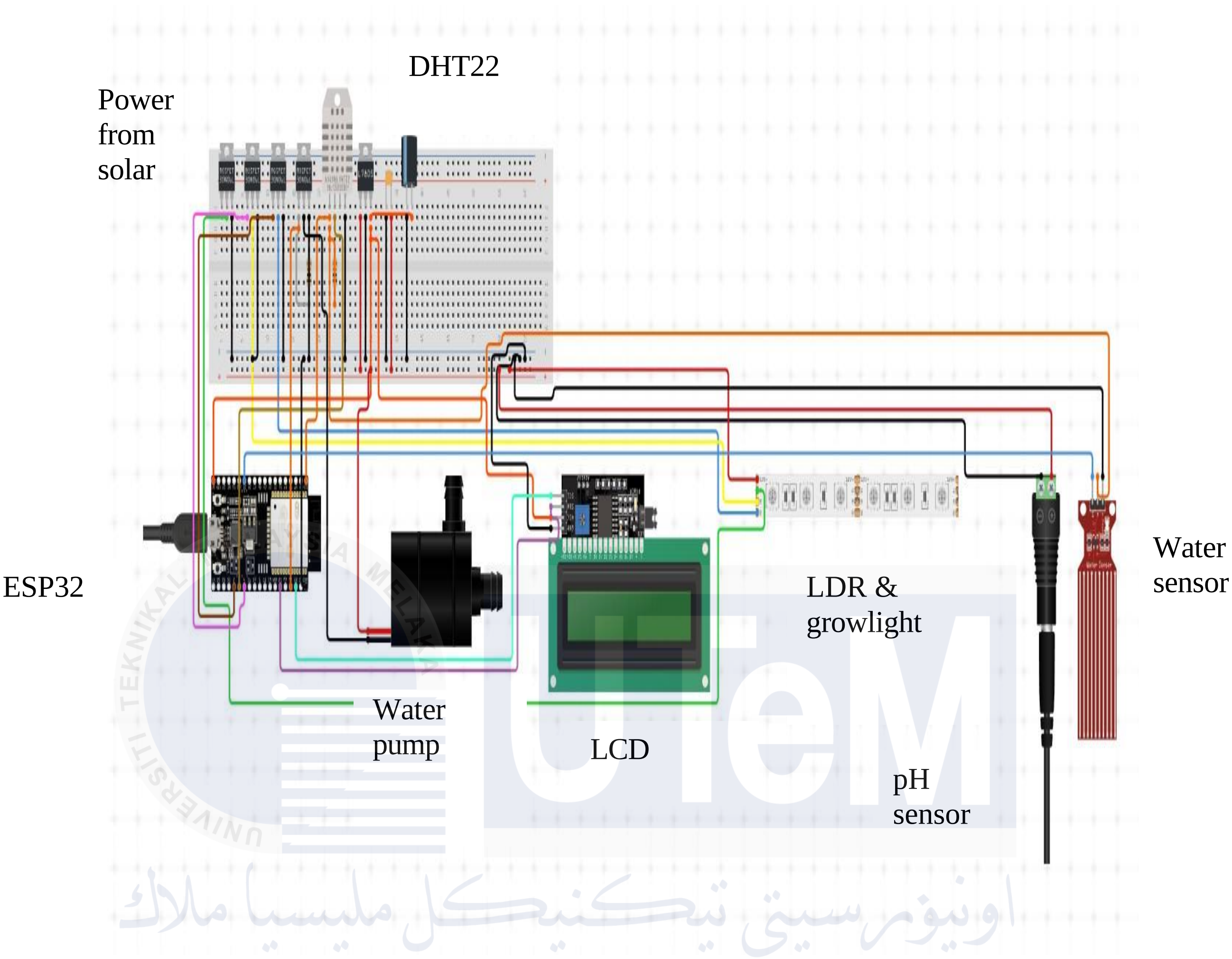


Figure 3. 21 Sensors wiring circuit diagram

The circuit shows the connection made in circuit drawing software where the main component ESP32 connected with the various sensors input and output.There are pH sensor to measure water nutrient ,DHT22 sensor which is for temperature and humidity reading ,LDR sensor to detect light intensity ,current sensor , water level sensor to detect water level on plant tank .Water pump and ph pump connected with relay and rechargable battery for pumping of nutrient water. Main power source comes solar panel straight to solar charger control then goes to battery and ESP32 microcontroller.LCD acts as output and will display values of reading .LED grow light will work if the sunlight level is very low .

3.5.3 DHT22 connection

The DHT22 sensor, which measures temperature and humidity, is connected to the ESP32 microcontroller via its DATA pin, typically to GPIO4, while the VCC and GND pins are connected to the 3.3V and GND pins of the ESP32, respectively. The ESP32 processes the sensor data and communicates it to an LCD display using the I2C protocol. The LCD's SDA and SCL pins connect to the ESP32's GPIO21 and GPIO22. This setup allows real-time monitoring of environmental conditions, with the LCD displaying current temperature and humidity levels, enhancing the efficiency and user-friendliness of the system.

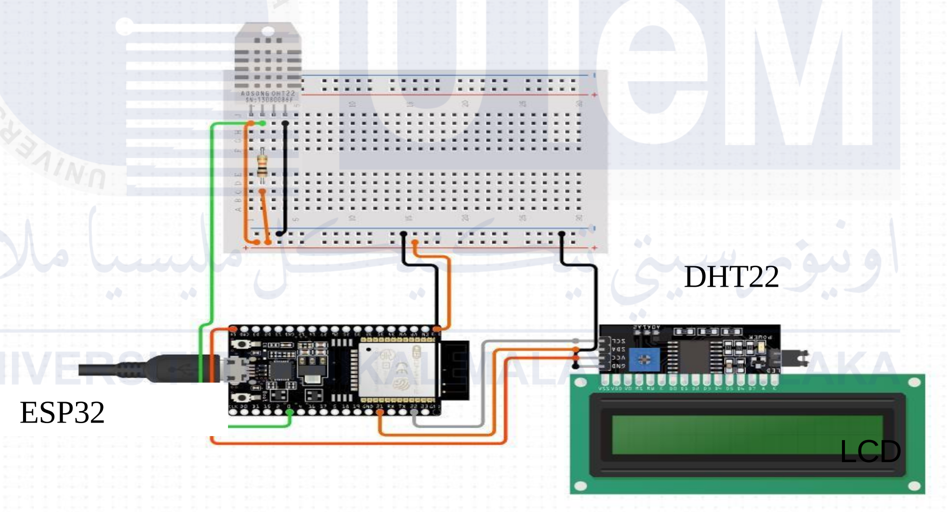


Figure 3. 22 DHT22 wiring circuit diagram

3.5.4 Water level sensor

The ESP32 microcontroller connected to a water level sensor to monitor and maintain the nutrient solution levels in the soilless cultivation system. The water level sensor typically has three pins which is (VCC, GND, and SIG). The VCC pin is can be connected to the 3.3V or 5V power supply of the ESP32, and the GND pin is connected to the ground of the

ESP32. The SIG pin, which sends the water level data, is connected to one of the digital GPIO pin on the ESP32, such as GPIO5. The ESP32 reads the signal from the water level sensor, processes the data to determine the current water level, and triggers appropriate actions, such as activating a water pump to refill the reservoir when the water level is low. This integration ensures that the plants receive a consistent supply of nutrient solution, crucial for their growth and health.

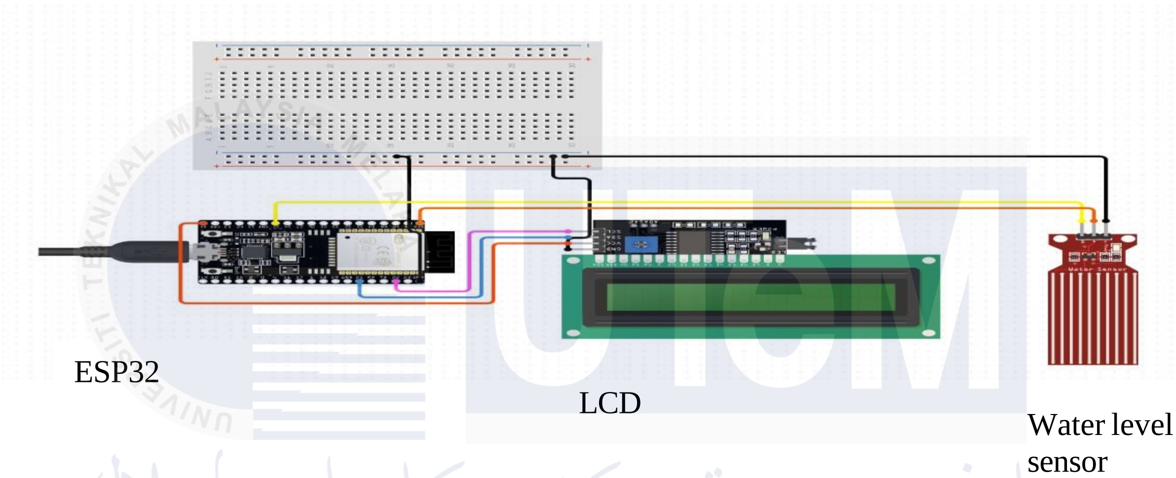


Figure 3. 23 water level sensor circuit diagram

Summary

The methodology chapter outlines the designs and implementation of a solar powered soilless cultivation system integrated with IoT technology. Key parameters such as temperature, humidity, pH levels, light intensity, and nutrient concentrations are continuously monitored using sensors like the DHT22 and water level sensors. These sensors are connected to an ESP32 microcontroller, which processes the data and triggers automated actions to maintain optimal growing conditions. The ESP32 also interfaces with an LCD for real-time data display and utilizes the I2C protocol for efficient communication. This systematic approach ensures a sustainable, efficient, and user-friendly solution for urban agriculture

CHAPTER 4

RESULT AND DISCUSSIONS

4.1 Introduction

This chapter is about result of project and presented. It includes of circuit development simulation development , project development and code development, This result based on initial state of project.

4.2 3 Design of the Soilless Cultivation System

The completed soilless cultivation system integrates essential components for an efficient, compact, and sustainable indoor farming solution. The system is powered by a 12V, 3W polycrystalline solar panel, connected to a solar charge controller that regulates energy flow to a 12V rechargeable battery, ensuring uninterrupted operation. The ESP32 microcontroller manages inputs from sensors and automates system operations. Key sensors include the DHT22 for temperature and humidity, a pH sensor for acidity levels, a water level sensor to monitor water availability, and a current sensor to track energy flow. A relay module controls the water pump and LED grow light, with power supplied by the battery. A buck booster steps down voltage to provide 5V for the LED grow light and 12V for the pumps. The LDR sensor activates the grow light during low light conditions, while the LCD display shows real-time data, including temperature, humidity, pH, water level, voltage, and current. The water and pH pumps work together to circulate nutrients and maintain optimal growing conditions. This compact system, powered by renewable energy, allows urban households to grow plants sustainably, addressing space constraints and reducing dependence on traditional farming practices.

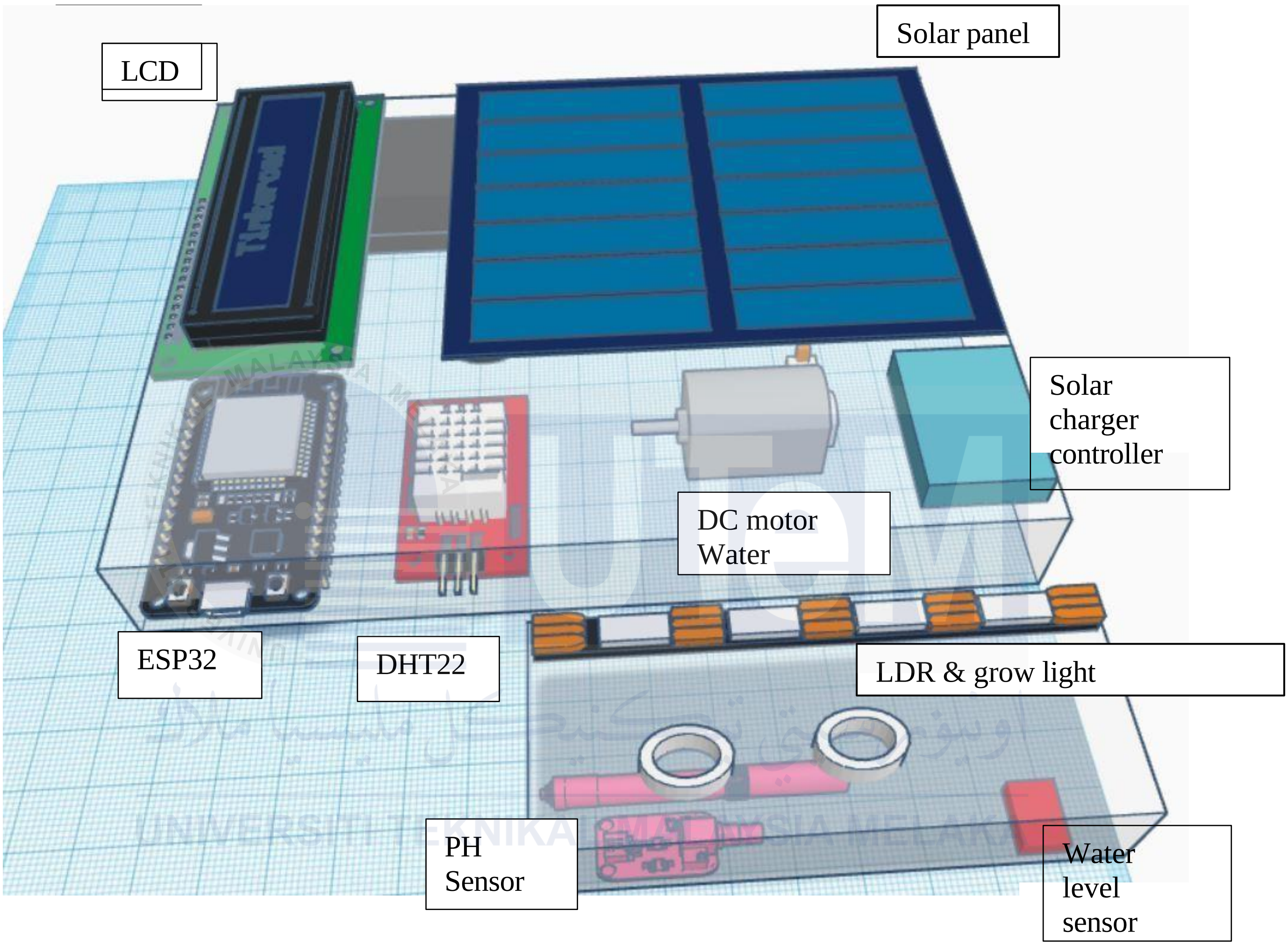


Figure 4.1 3d Design of project

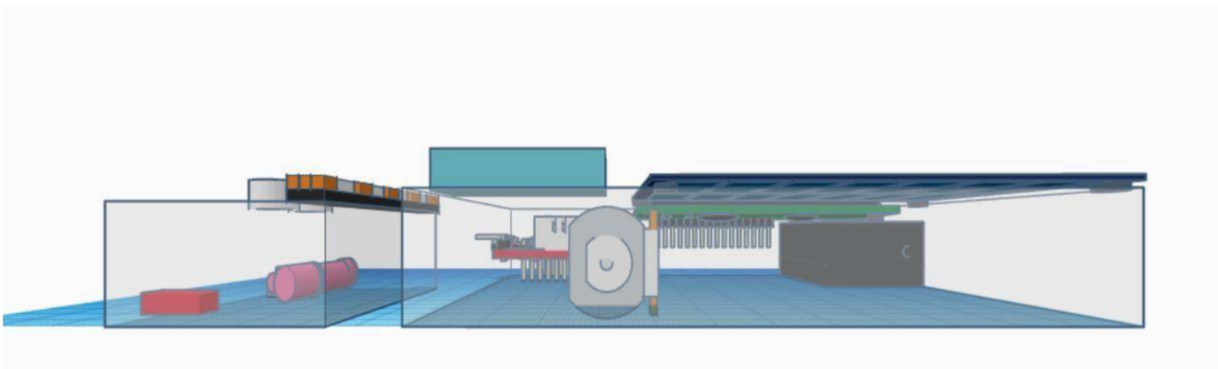


Figure 4.2 side view of 3d design

4.2.2 Hardware of system

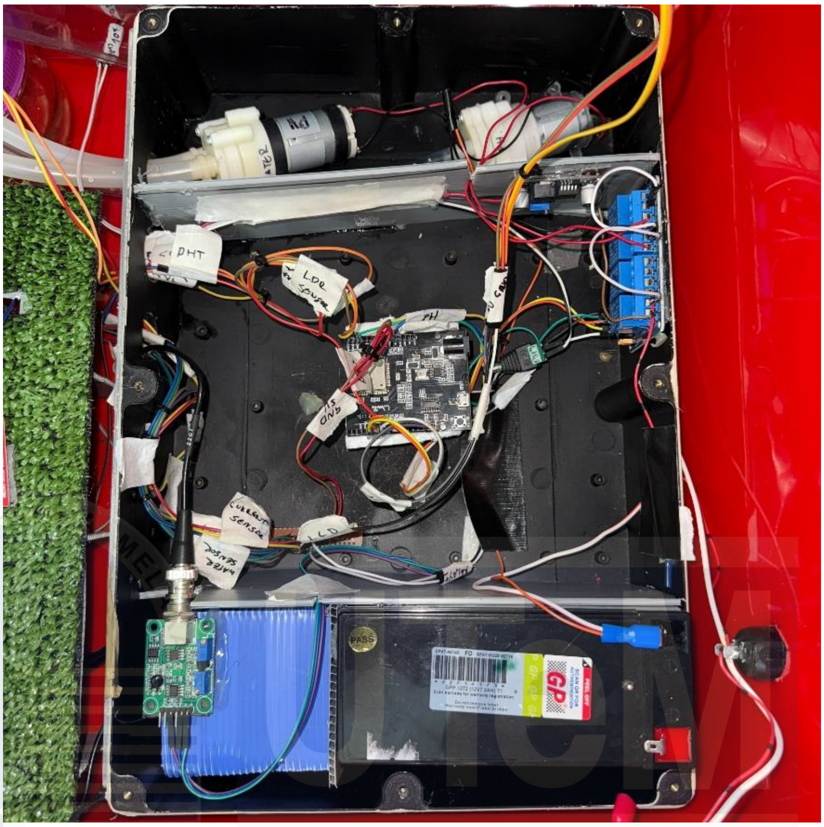


Figure 4.3 view of wiring system

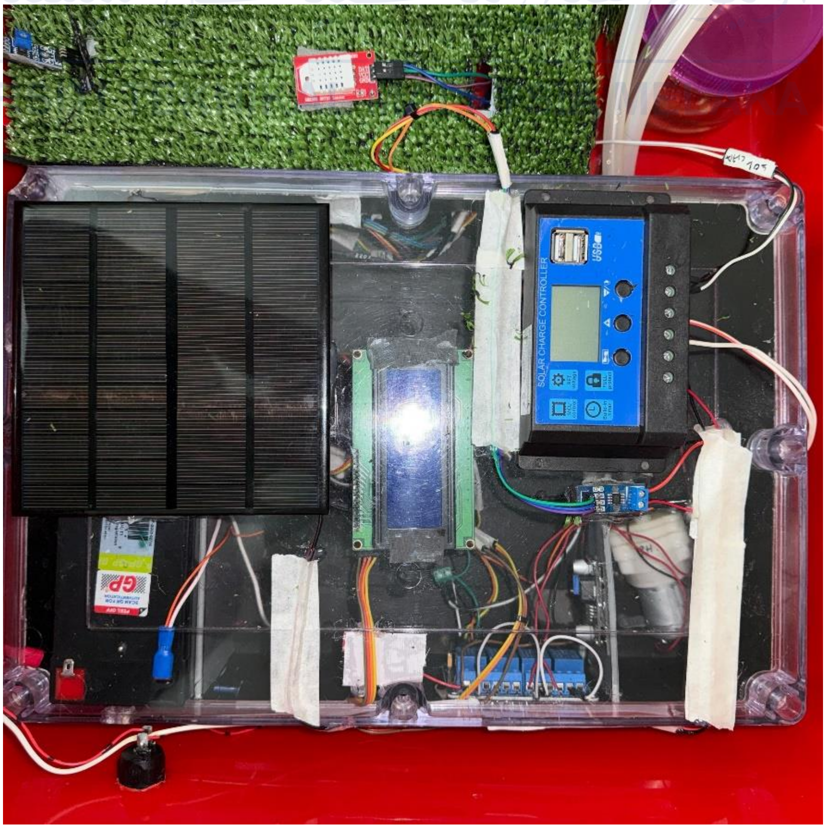


Figure 4.4 Top view of hardware system

Figure 4.5 Top view of full system

Figure 4.6 Side view of full system

4.3 Data collection

4.3.1 Temperature and Humidity Testing Using DHT22 Sensor

Environmental monitoring is a critical aspect of soilless cultivation systems, as temperature and humidity significantly influence plant growth, nutrient uptake, and overall system efficiency. In this project, the DHT22 sensor was employed to monitor these environmental parameters in a controlled indoor setting. The testing focused on capturing data at different times of the day (morning, evening), and night to evaluate natural environmental fluctuations and the sensor's performance.

The testing was conducted under typical indoor conditions, where ventilation, such as a fan, was continuously operational to simulate a household setup. This ensured steady air circulation and highlighted the DHT22 sensor's ability to adapt to variations in temperature and humidity. The primary objective was to validate the sensor's reliability in providing accurate data that could assist in optimizing automated soilless cultivation systems.

This analysis provides insights into the environmental dynamics indoors, reflecting the suitability of the DHT22 sensor for maintaining optimal growth conditions in confined spaces. By observing the sensor's ability to detect changes in temperature and humidity, the data demonstrates its importance in automating critical system functions, such as irrigation and lighting control. The data recorded from the DHT22 sensor is summarized in the table below, showcasing temperature and humidity variations across different times of the day:

Table 4.1 Dht22 reading

TIME	TEMPERATURE (C)	HUMIDITY (%)
MORNING	29.4	82
EVENING	30.7	77
NIGHT	29.6	88

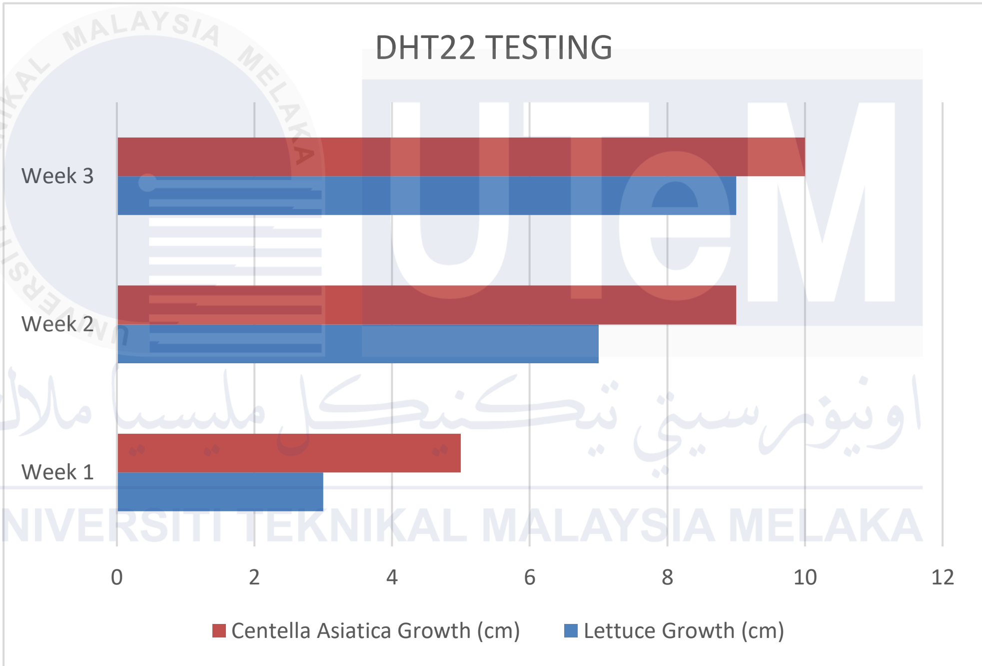


Figure 4.7 Dht22 testing

- Temperature: The highest temperature (28.5°C) was recorded in the evening due to heat accumulation indoors, while the lowest temperature (27.0°C) occurred at night when cooling effects dominated.
- Humidity: Humidity was highest (68%) at night as lower temperatures reduced evaporation, while it dropped to 60% in the evening due to increased heat.

4.3.2 Calibration of PH sensor

PH sensor calibrate it first before installing in project.The pH sensor was calibrated using distilled water and nutrient water to ensure accurate readings for the hydroponic system. Distilled water, with a neutral pH of 7.0, was used as the reference point for calibration, while nutrient water was used to verify the sensor's response in real-world conditions. This ensures reliable pH monitoring in both neutral and nutrient-rich solutions.

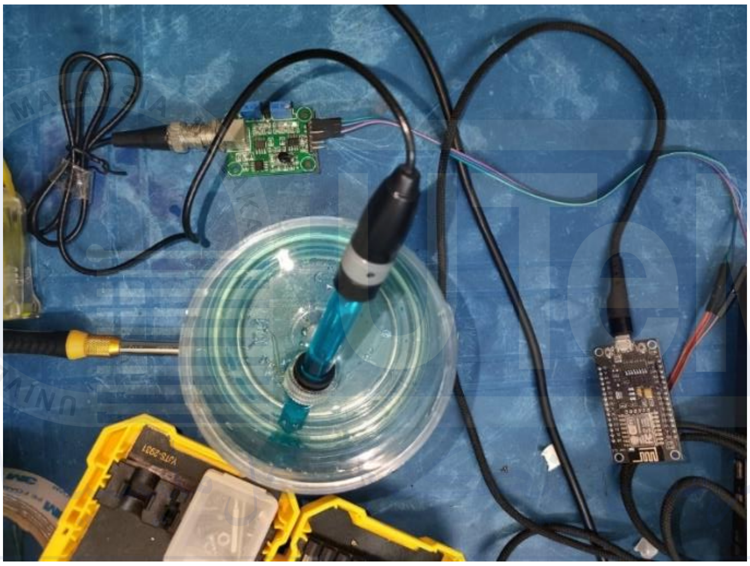


Figure 4.8 PH sesnsor calibration

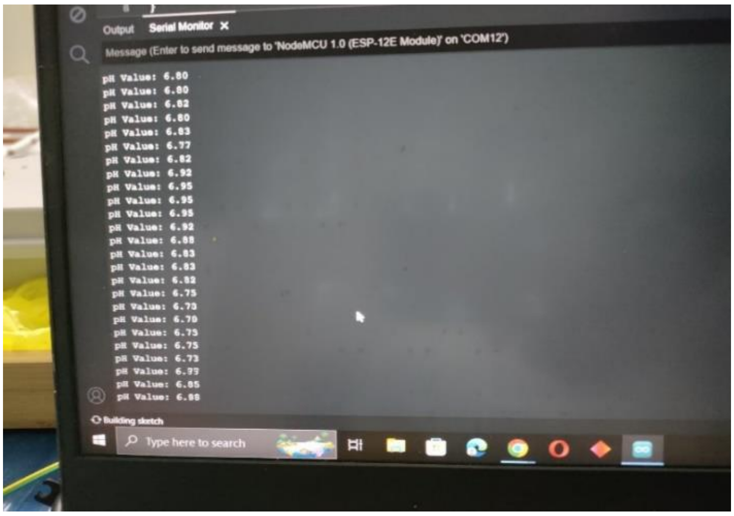


Figure 4.9 PH calibration reading on serial monitor

4.3.4 pH sensor testing with the plants

Monitoring pH levels is a vital component of soilless cultivation systems, as nutrient absorption is directly influenced by the acidity or alkalinity of the solution. The optimal pH range for plant growth in most soilless systems typically falls between 5 and 8, where nutrient availability is maximized. However, the pH of nutrient-rich water can fluctuate over time due to factors such as nutrient buildup, microbial activity, and evaporation.

pH Monitoring Analysis

In the initial stage (Days 1–3), the pH levels were observed to remain stable within the range of 5.8–6.2. This stability can be attributed to the freshly added nutrient water, which is well-balanced and close to neutral. During this phase, the nutrient solution provides optimal conditions for plant growth, as the pH is within the ideal range for nutrient absorption. The pH sensor demonstrated accurate readings during this stage, confirming its reliability in monitoring stable pH levels.

In the mid-stage (Days 4–6), a slight increase in pH levels was recorded, ranging from 6.4 to . This change is a result of chemical interactions between the dissolved nutrients and the environment within the soilless cultivation system. The gradual rise remains within acceptable limits, but it signals the beginning of nutrient buildup and potential changes in water chemistry. Monitoring during this phase ensures that any significant pH shifts can be addressed before they impact plant health.

In the late stage (Days 7–10), pH levels increased further, reaching 7.4–10.3. This rise is primarily due to the accumulation of salts, nutrients, and evaporation over time, which can push the pH beyond the optimal range. If left unmanaged, such conditions could reduce nutrient availability, leading to plant stress. The pH sensor effectively captured these variations, highlighting the importance of regular monitoring and timely corrective actions, such as water replacement or pH buffering, to maintain a suitable growing environment.

Table 4.2 PH sensor reading

DAY	PH LEVEL	CONDITION
1	5.4	FRESH
2	5.7	FRESH
3	5.6	FRESH
4	5.8	FRESH
5	5.9	FRESH
6	6.5	MODERATE BUILDUP
7	6.7	MODERATE BUILDUP
8	7.9	HIGH BUILDUP
9	8	NEED TO CHANGE
10	8	NEED TO CHANGE

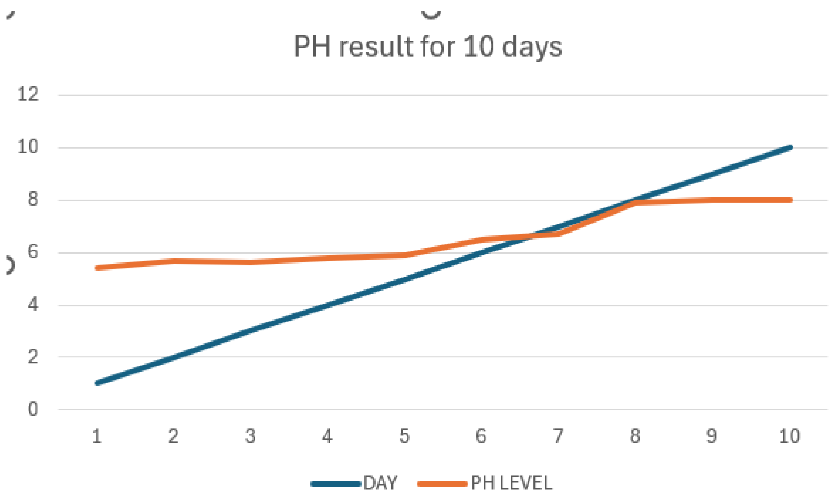


Figure 4.10 Ph result for 10days

Figure 4.11 Inside tank after cleaning

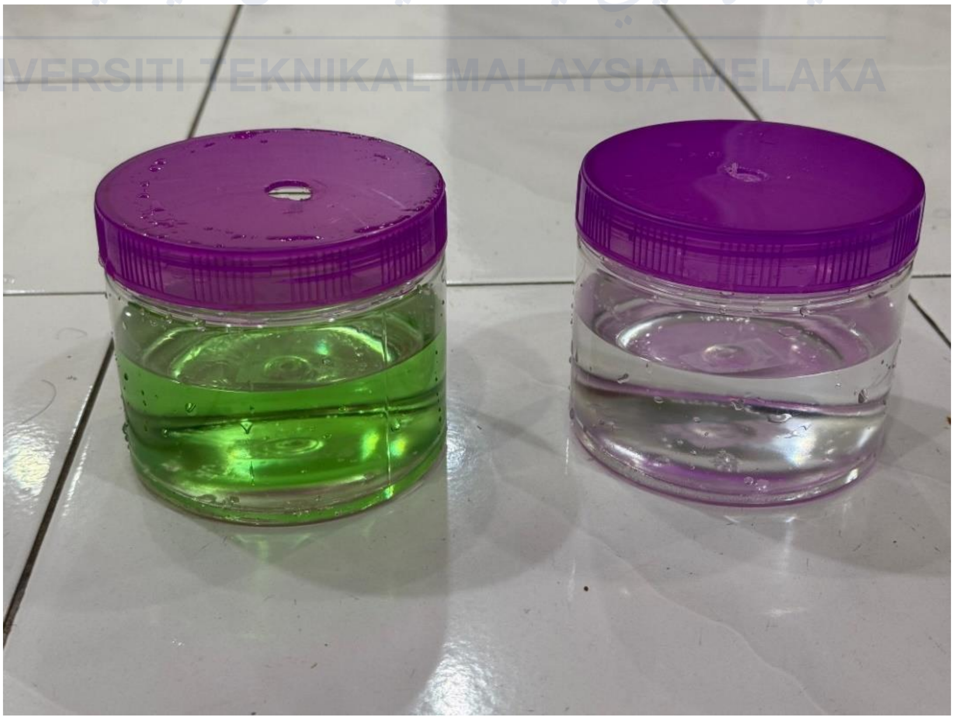


Figure 4.12 Fresh water and plant nutrient water

4.3.5 Water Level Sensor Testing

Water Level Sensor Analysis

The water level sensor is a critical component in ensuring that the plants receive an adequate supply of nutrient water in this soilless cultivation system. The sensor is designed to monitor water levels within the reservoir and categorize them into three conditions: low (0–29%), moderate (30–40%), and sufficient (above 40%). Whenever the water level falls below 30%, the water pump is triggered to refill the tank, maintaining optimal hydration for the plants. Over time, as the plants absorb water and evaporation occurs, the water level gradually decreases. This trend underscores the importance of timely refilling and effective monitoring. For this analysis, water levels were observed and recorded over a 10-day period.

Figure 4.14 Shows water on app and lcd display

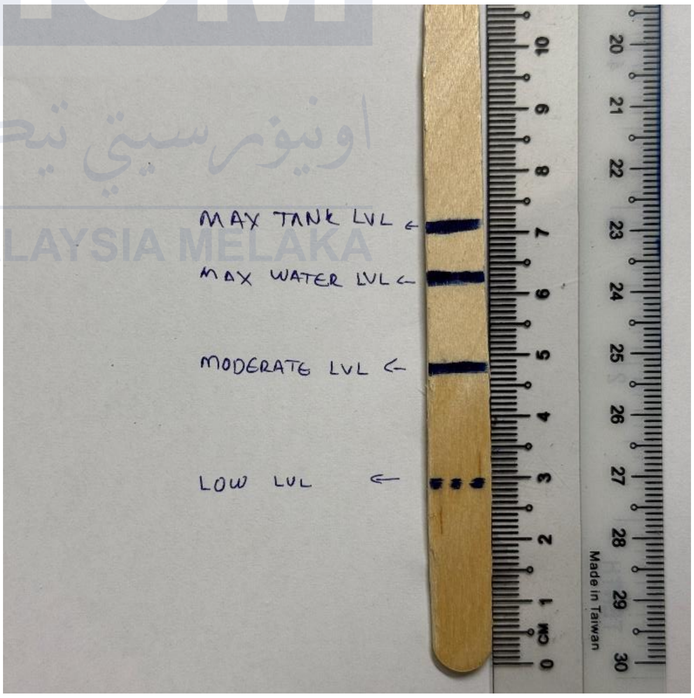


Figure 4.13 Water level distance inside tank

Table 4.3 Water level sensor reading

DAY	WATER LEVEL	CONDITION
1	50	SUFFICIENT
2	48	SUFFICIENT
3	46	SUFFICIENT
4	44	SUFFICIENT
5	42	SUFFICIENT
6	39	MODERATE
7	36	MODERATE
8	33	MODERATE
9	29	LOW
10	28	LOW

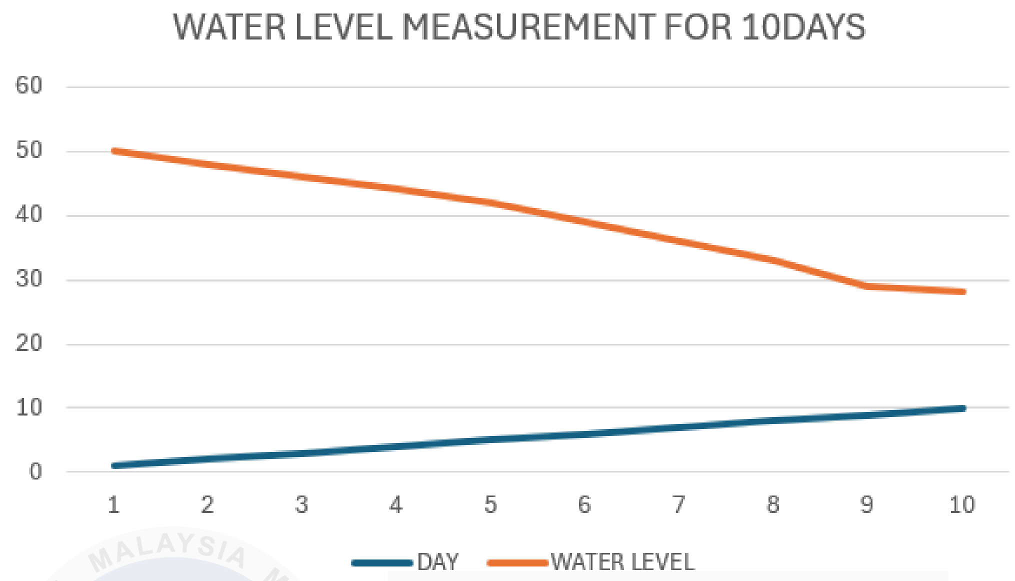


Figure 4.15 Water level measurement for 10days

The water level (red line) decrease day by day . After 5days(blue line) ,water level drops significanly.

4.3.6 Light-Dependent Resistor (LDR) Sensor Analysis

The LDR sensor plays a vital role in optimizing the lighting system of the soilless cultivation project. It monitors the availability of natural sunlight and ensures that the grow lights are activated only when necessary, conserving energy and providing consistent illumination for plant growth. For sunny days, the LDR detects sunlight during the morning, afternoon, and evening, ensuring the grow lights are deactivated. At night, when no sunlight is detected, the grow lights automatically turn on. On rainy or cloudy days, where sunlight is absent, the LDR fails to detect light throughout the day, activating the grow lights for 24 hours to maintain optimal lighting for the plants

Table 4.4 LDR sensor reading during sunny days

TIME (SUNNY DAYS)	LDR READING (SUNLIGHT DETECTED)	GROW LIGHT STATUS
MORNING	YES	OFF
AFTERNOON	YES	OFF
EVENING	YES	OFF
NIGHT	NO	ON

Table 4.5 LDR sensor reading during rainy days

TIME (RAINY DAYS)	LDR READING (SUNLIGHT DETECTED)	GROW LIGHT STATUS
MORNING	NO	YES
AFTERNOON	NO	YES
EVENING	NO	YES
NIGHT	NO	YES

4.3.7 Solar Panel Efficiency and Battery Performance

The solar panel is the primary energy source for the soilless cultivation system, providing renewable energy to ensure the system's sustainability. The project utilizes a 3W, 12V, 250mA polycrystalline solar panel connected to a 12V rechargeable battery through a solar charge controller. The charge controller regulates the power flow, protecting the battery and ensuring efficient energy storage. This section discusses the charging efficiency, operational duration, and energy requirements of the system.

Efficient energy management is crucial for an IoT-based soilless cultivation system to operate independently and sustainably. The solar panel charges the battery during the day, storing energy to power the system components, including the water pump, LED grow lights, and sensors. The battery ensures continuous operation even during non-sunny periods, such as rainy days or nighttime. This analysis examines the solar panel's ability to recharge the battery, the time required for a full charge, and how long the system can run on a fully charged battery.

Figure 4.16 Solar charger controller reading

Battery Charging Time Calculation

The 12V rechargeable battery, commonly used in small-scale renewable energy systems, has an estimated capacity of 7Ah. Its energy storage potential can be calculated .

Battery Capacity in Watt-Hours (Wh):

Battery Capacity = Voltage x Amp-hours

= 12v x 7ah = 84WH

Solar Panel Power Output

The solar panel generates a maximum of 3W under ideal conditions. Accounting for energy losses in the charge controller and environmental inefficiencies, only 80% of this power is effectively used.

Effective solar panel output = 3W x0.8 =2.4W

Charging time = Battery capacity / Effective solar panel output

84W/ 2.4W

=35 hours

System Energy Consumption and Battery Duration

Water Pump: Operates for 5 minutes (0.083 hours) per day.

Pump Energy Use=5W×0.083h=0.415Wh

pH Pump: Operates for 2 minutes (0.033 hours) per day.

pH Pump Energy Use=5W×0.033h=0.165Wh

Table 4.6 Solar power output

TIME	*VOLTAGE(V)*	*CURENT (A)*	*POWER OUTPUT (W)*
MORNING	10	0.20	2.1
AFTERNOON	12	0.25	3.0
EVENING	8.5	0.15	1.3

LED Grow Light: Runs for 12 hours per night.

LED Energy Use=3W×12h=36Wh

Sensors and Microcontroller: Operate continuously for 24 hours per day.

Sensors Energy Use=1W×24h=24Wh

Total Daily Energy Consumption:

Total Consumption=0.415Wh+0.165Wh+36Wh+24Wh=60.58Wh

= 0.415Wh + 0.165Wh + 36Wh + 24Wh **= 60.58Wh**

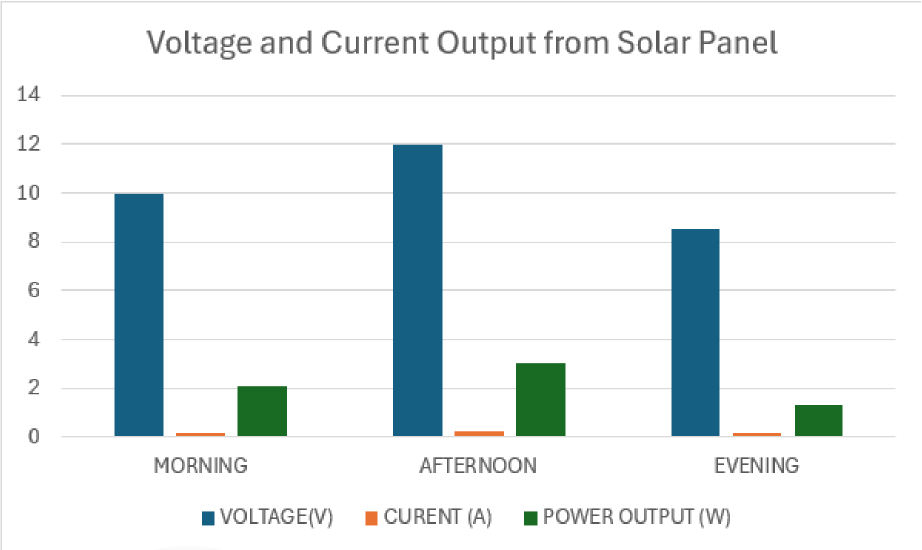


Figure 4.17 Voltage and current output solar panel

4.4 Analysis of Power Consumption

This analysis evaluates the power consumption and solar panel efficiency of the small-scale indoor soilless cultivation system and compares it with similar systems documented in existing studies. The proposed system was designed to operate efficiently under indoor conditions, where sunlight exposure is limited, requiring a robust yet minimalistic setup for energy management. Unlike existing systems designed for outdoor or semi-outdoor applications that use larger solar panels and batteries, this system prioritizes energy efficiency and compactness, making it ideal for small urban spaces. Its lower energy consumption and reliance on a 3W solar panel demonstrate that sustainable indoor cultivation can be achieved with significantly fewer resources compared to larger systems.

Justification of Improvement

Existing systems such as those by Smith et al. (2021) and Liu et al. (2020) rely on larger solar panels (30–50W) and higher-capacity batteries (10–18Ah), designed to handle higher energy loads. These setups often face limitations in urban settings due to space constraints and high initial costs. The proposed system, in contrast, achieves similar functionality using only a 3W solar panel and a 12V, 7Ah rechargeable battery, reducing the overall system size and cost. By utilizing energy-efficient components and a targeted power management strategy, this system ensures continuous operation while maintaining sustainability, even in limited sunlight conditions. This innovation bridges the gap between functionality and affordability, making soilless cultivation systems more accessible to urban users.

Comparison with Existing Systems

A study by Smith et al. (2021) on solar-powered hydroponic systems for small-scale farming reported the use of a 50W solar panel and a 12V, 18Ah battery. The system powered grow lights, pumps, and sensors with a daily energy consumption of 240Wh. Similarly, Liu et al. (2020) analyzed a solar-powered system with a 30W panel and a 12V, 10Ah battery, which consumed around 120Wh/day. In contrast, the proposed system demonstrates reduced energy consumption of 57Wh/day while maintaining functionality, as detailed in the table below.

Table 4.7 Comparison of Solar energy consumption

Study	Solar panel rating	Battery capacity	Daily energy consumption	Components powered
Smith et al(2021)	50w	12v,18Ah	240Wh	Pumps ,grow light
Liu et al (2020)	30 w	12v,10Ah	120Wh	Pumps, basic sensor
Proposed system	3w	12v,7A h	57Wh	Pumps, sensor,led grow light

Solar Panel Energy Generation Comparison

Solar panel efficiency was analyzed based on energy generation throughout the day. Studies report that larger systems with 30–50W panels can generate up to 120Wh/day under optimal conditions (Liu et al., 2020). In comparison, the proposed 3W panel generates approximately 27.72Wh/day, sufficient for recharging the battery over three days. This slower recharge time is compensated by the system's lower power demands, ensuring that the battery can support continuous operation without frequent recharging. The compact and low-cost solar panel design is a significant advantage for urban indoor users.

Table 4.8 Comparison of estimated solar recharge days

Study	Solar panel rating	Daily energy generation	Estimated recharge days	Components powered
Smith et al(2021)	50w	120Wh	2days	Outdoor hydroponic
Liu et al (2020)	30 w	70Wh	2.5days	Small Hydroponic
Proposed system	3w	27.72 Wh	3days	Indoor system

Efficiency and Practicality

The proposed system excels in energy efficiency and practicality for indoor applications. Unlike larger systems, which may face issues of excess energy wastage or increased costs, this system carefully matches energy supply with demand. Its design aligns with the needs of urban growers, offering a low-cost, space-efficient alternative without compromising functionality. The use of a smaller solar panel and battery makes this system more sustainable and accessible, proving its relevance in modern, resource-limited settings.

4.5 Analysis of Real-Time Monitoring and Data Access via IoT Application

This analysis focuses on the effectiveness of real-time monitoring and data access for the soilless cultivation system through the IoT application developed using MIT App Inventor. The application provides users with live updates on key environmental parameters such as temperature, humidity, water level, pH, light intensity, voltage, and current. These values are transmitted via Bluetooth communication, offering a user-friendly interface to monitor the system. Unlike traditional systems where manual intervention is required for observation and data collection, this system automates monitoring, enhancing accuracy and user convenience.

Justification of Improvement

Conventional hydroponic systems typically rely on manual sensors and physical inspections to monitor environmental parameters, leading to inefficiencies and delayed responses to changes. Systems like Ghosh et al. (2020) utilized semi-automated setups where users still needed to log into web portals to retrieve data. In contrast, the proposed system employs a mobile IoT application for direct, real-time data access. This eliminates the need for intermediate steps and provides instant feedback, enabling users to address system issues immediately. This feature improves the overall efficiency and reliability of the system, making it more appealing for both beginners and experienced growers.

Comparison with Existing Systems

Existing studies highlight various approaches to data monitoring in hydroponic systems. Ghosh et al. (2020) implemented a web-based monitoring system requiring stable internet connections and desktop devices, which limited mobility and ease of access. Similarly, Chen et al. (2019) developed a cloud-based system reliant on Wi-Fi, introducing latency issues in data transmission. The proposed system bypasses these limitations by using Bluetooth communication, providing near-instantaneous data updates without dependency on internet connectivity. The table below compares the proposed system with these existing methods.

Table 4.9 Comparison of data monitoring methods

Study	Monitoring method	Connectivity	Update duration
Ghostet al (2020)	Web based	Internet	Moderate
Chen et al (2020)	Cloud based	Internet	Delayed
Propose system	Mobile app	Bluetooth	Instant

Efficiency and Practicality

The proposed system significantly improves ease of use and accessibility by allowing users to monitor data directly on their mobile devices. Unlike web or cloud-based systems, which can suffer from connectivity issues or delays, the Bluetooth-based application ensures instant feedback within a local range. This feature is particularly advantageous for indoor soilless cultivation, where close proximity to the system is typical. Additionally, the application provides a visual dashboard, making it easy for users to interpret data trends without requiring advanced technical knowledge.

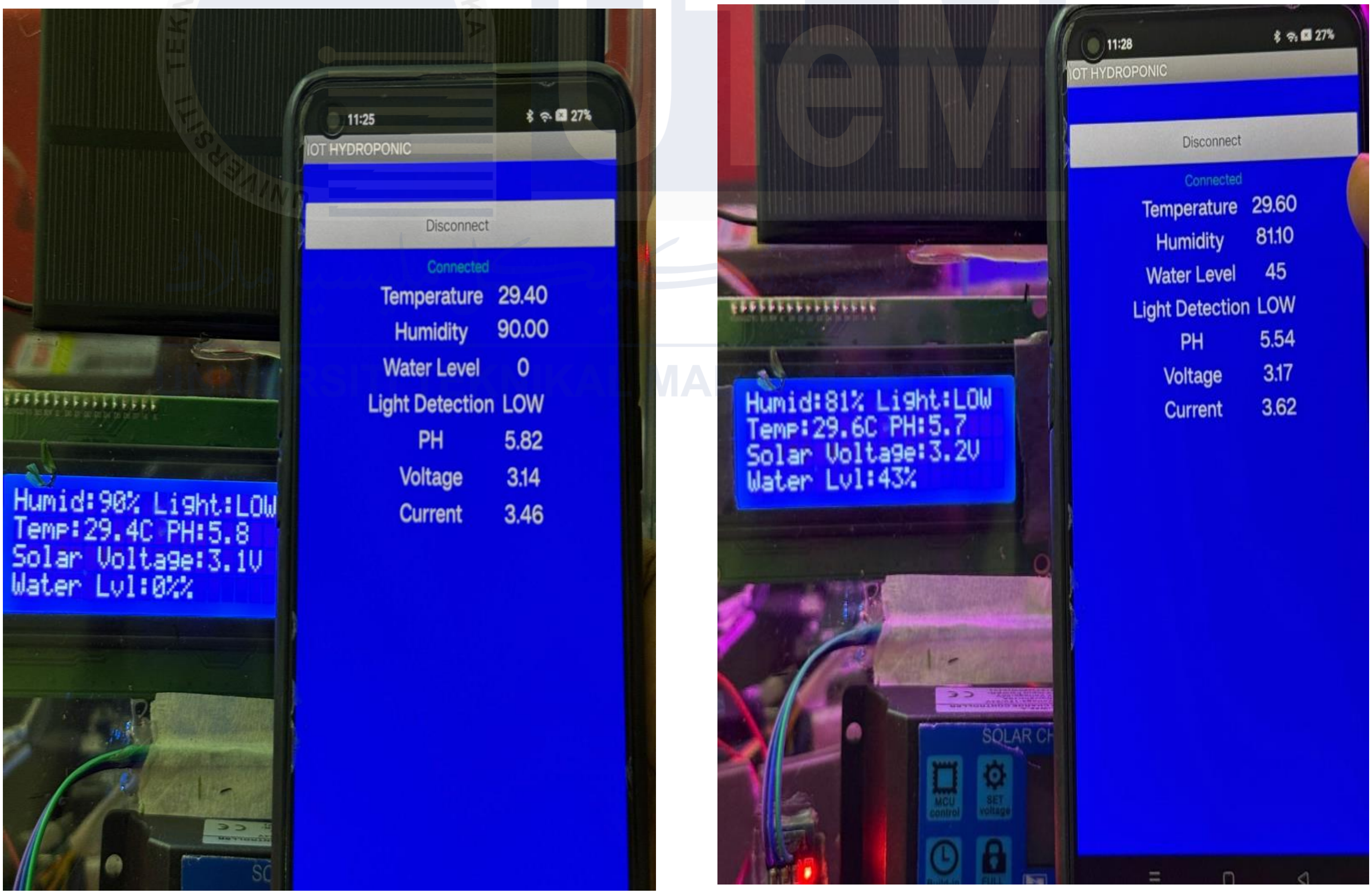


Figure 4.18 IoT app updates on reading

Practical Comparison

The proposed system outperforms traditional setups by offering real-time insights and eliminating manual errors. For example, Ghosh et al. (2020) reported delays of up to 30 minutes in updating data due to network latency, leading to potential risks for sensitive plants. By using a Bluetooth connection, the proposed system reduces this delay to under 5 seconds. Furthermore, the mobile app enhances user convenience by consolidating all parameters into a single interface, reducing the need for separate devices or systems.

Table 4.10 Comparison of data update duration

Feature	Ghost et al(2020)	Chen at al (2020)	Proposed system
Update speed	30 Mins	40Mins	5Sec
Connectivity	Internet	Internet	Bluetooth
User interface	Web based	Cloud based	Mobile app
Accessibility	Limited to desktop	Limited by wifi	Portable

The proposed real-time monitoring system offers significant improvements in accessibility, reliability, and ease of use compared to existing methods. By integrating a Bluetooth-enabled mobile app, the system eliminates the limitations of internet dependency and delayed updates, making it an ideal solution for urban growers seeking a user-friendly and efficient soilless cultivation system.

4.6 Analysis of Compact Indoor Soilless Cultivation System

This section evaluates the advantages of the proposed compact soilless cultivation system, which integrates essential sensors, solar power, and pumps to optimize plant growth and freshness. The system combines environmental monitoring, automation, and renewable energy to maintain plant health and extend freshness efficiently. The project's small-scale, indoor-friendly design makes it highly accessible for urban households, differentiating it from existing systems that often lack either compactness or complete sensor integration.

Justification of Improvement

Existing soilless cultivation systems are often designed for larger-scale operations or lack critical components. For example, Zhang et al. (2020) and Rahman et al. (2019) implemented semi-automated systems but omitted comprehensive environmental monitoring or renewable energy solutions. The proposed system addresses these gaps by integrating DHT22 for temperature and humidity, a pH sensor, a water level sensor, and an LDR for light detection. Additionally, it includes a 3W 12V solar panel and rechargeable battery to power the system, along with a water pump and pH adjustment pump for automated control of water and nutrient delivery. This ensures continuous monitoring, efficient energy use, and automation, making it a significant improvement over existing systems.

Table 4.11 Comparison of compact hydroponic methods

Study	Sensors	Automation level	Environment
Zhang et al (2021)	Temperature, humidity,water level,grow light,solar panel	Minimum	Very large scale indoor
Rahman et al (2020)	water level,grow light,solar panel,water pump ,	semi	Outdoor
Proposed system	Temperature, humidity,water level,grow light,solar panel,water pump ,pH pump	Fully	Small scaled indoor

4.7 Plant Growth and Freshness Analysis

The growth and freshness of plants in the compact soilless cultivation system were closely monitored over the course of two months to evaluate its effectiveness in supporting healthy plant development. Lettuce plants grown in this system demonstrated steady growth and exceptional freshness, attributed to the precise environmental controls provided by the integrated sensors and automated system components.

The system successfully maintained optimal conditions, allowing the lettuce plants to grow from seedlings to their mature height of 15–18 cm within two months. This growth progression was supported by continuous monitoring and adjustment of water levels, pH balance, and light intensity. The combination of solar-powered LED grow lights and an efficient water and nutrient delivery system contributed significantly to this good growth.

The system also played a critical role in maintaining plant freshness during the later stages of growth. By ensuring consistent hydration and nutrient availability, the plants retained their vibrant green color and crisp texture even as they approached full maturity. The controlled environment minimized exposure to stress factors, such as irregular watering or nutrient deficiencies, commonly seen in less automated systems.

Additionally, the system's compact design and automated functionalities ensured that the plants could thrive in a controlled indoor environment, making it highly suitable for urban households with limited space. The ability to replicate optimal growing conditions consistently reduced the risk of plant diseases and environmental stressors, further contributing to the overall health and quality of the plants.

This highlights the system's potential to provide a reliable solution for sustainable indoor farming, catering to both residential and small-scale commercial applications.

Table 4.12 Plant growth analysis

Weeks	Lettuce growth	Lettuce freshness	Centella growth	Centella freshness
1-2	3cm	Fresh and vibrant	5cm	Fresh and vibrant
3-4	6cm	Healthy and noticeable growth	10cm	Healthy and noticeable growth
5-6	9cm	Dense leaf formation	15cm	Spreading leaves
7-8	12cm	Fully mature	18cm	Lush and spreading

4.7.1Analysis and Observation

Lettuce Growth

The lettuce plants demonstrated consistent growth over the eight-week period. Starting from an average height of 3 cm during the first two weeks, the plants reached their maximum growth of 12 cm by the seventh and eighth weeks. Dense leaf formation was observed after Week 4, showcasing the system's ability to sustain rapid growth under controlled conditions. This steady growth pattern emphasizes the efficiency of the system in maintaining optimal environmental parameters, ensuring the plants achieved their full potential within the expected timeframe.

Figure 4.19 lettuce growth after 6weeks

Figure 4.20 lettuce growth after 8weeks

Centella Asiatica Growth

Centella Asiatica (Pegaga) grew at a slightly faster rate compared to lettuce in the initial weeks, starting at 5 cm during Weeks 1–2 and reaching a height of 18cm by Weeks 7–8. The spreading and dense leaves observed after Week 4 highlighted the effectiveness of the system in maintaining optimal growth conditions.

Figure 4.21 cantella growth comparison

Freshness

Both lettuce and Centella Asiatica retained their freshness throughout the growth period. The controlled water, nutrient, and light levels ensured vibrant and healthy plants at all stages of growth.This analysis underscores the ability of the compact soilless cultivation system to provide consistent growth and maintain plant freshness, making it an effective solution for indoor plant cultivation.

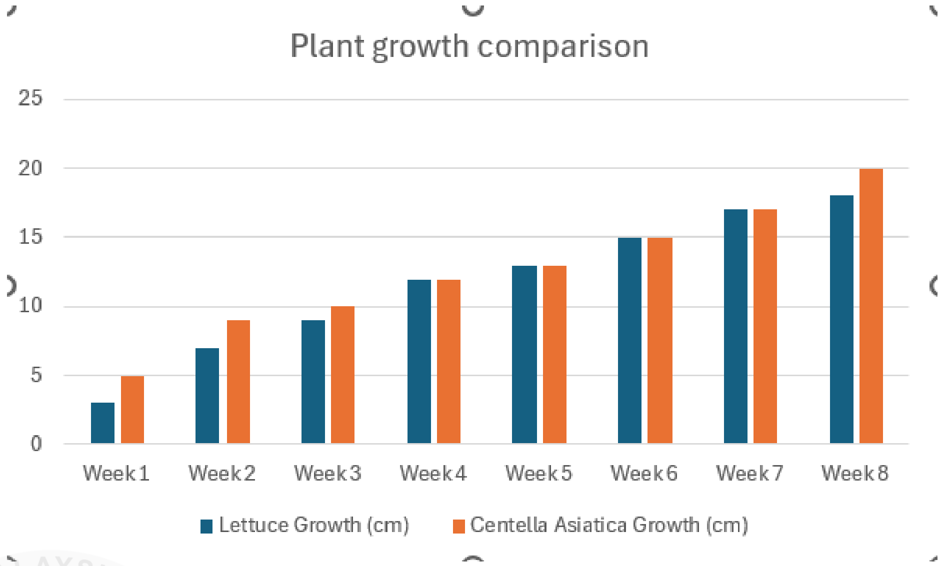


Figure 4.22 Cantella and lettuce growth comparison

4.8 Scalability and Space Efficiency Analysis

Rapid urbanization and deforestation have led to the destruction of natural forests and agricultural lands, primarily to make way for housing developments, industrial projects, and urban construction. This has resulted in a significant reduction in available soil space, especially for those living in urban areas like apartments and condominiums. Such residents often lack the option to grow plants or vegetables in their homes due to space limitations.

The proposed small-scale soilless cultivation system addresses these challenges effectively. It is compact, portable, and designed specifically for indoor use. This innovative solution allows individuals, even in urban environments with limited space, to grow plants such as vegetables and herbs in their homes. The system can help households save money by providing them with fresh, homegrown produce for cooking. It also promotes self-sufficiency and healthy eating habits, making it especially valuable for families with tight budgets or those looking for sustainable alternatives. This system not only supports sustainable living but also gives urban residents a chance to engage in home gardening without requiring land or soil. The soilless cultivation system can easily be placed in kitchens, balconies, or living rooms, making it accessible to everyone. Unlike traditional hydroponic systems that are bulky and often targeted at industrial-scale farming, this project focuses on compactness and affordability.

Table 4.13 Comparison of space efficiency

Features	Traditional hydroponic	Proposed system
Space requirement	Require large areas, often unsuitable for indoor uses.	Compact and ideal for small space indoor
Application	Focused on industrial - scale farming	Suitable for personal use by urban household
Flexibility	Fixed installation or hard to move since its bigger setup	Portable and adaptable for different indoor environment
Cost saving	High initial investment and maintenance	Low cost solution for growing home use vegetable
Environmental impact	Often limited to large agricultural project	Help reduce reliance on large scale deforesation

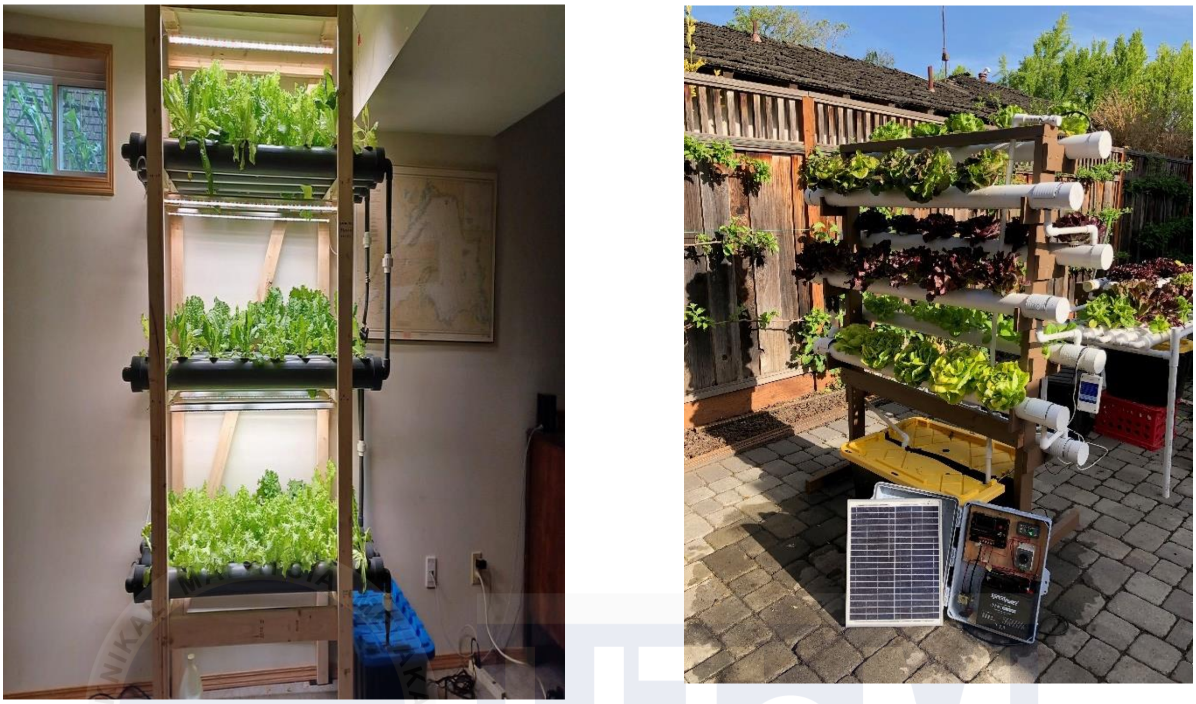


Figure 4.23 Traditional Indoor Hydroponic System

Figure 4.24 Proposed project

Summary

In summary , a comprehensive analysis of the results obtained from the development and testing of the soilless cultivation system. It begins by evaluating key parameters such as temperature and humidity, pH levels, water level, light detection, and power consumption, which were monitored and controlled using various sensors integrated into the system. The results demonstrate the system's efficiency in maintaining optimal conditions for plant growth over a defined period, supported by data presented in tables and graphs.

The chapter also highlights the system's innovative features, such as its compact design, use of solar power, and integration of multiple essential components like water and pH pumps, making it suitable for small-scale indoor applications. Comparative analyses emphasize the system's improvements over traditional methods, showcasing its ability to monitor and control parameters via a mobile app, offering users a seamless experience.

Additionally, this chapter underscores the system's efficiency in power management, with detailed calculations showing how solar energy sustains the system's operation. Growth analyses of lettuce and Centella asiatica further validate the system's performance, demonstrating significant progress in plant growth and freshness over time. These findings establish the reliability and effectiveness of the developed system, making it a sustainable and practical solution for indoor soilless cultivation.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, the project successfully achieved its primary objectives by developing a functional prototype of an IoT Solar Powered Soilless Cultivation System. The integration of various sensor which is temperature and humidity, pH , water level, current, and LDR sensor, ensured precise and efficient monitoring and control of the system. This sensor network allowed for automated and optimized operation, enabling consistent environmental conditions necessary for plant growth.

The system design effectively demonstrated the ability to manage the cultivation process through IoT-based monitoring and control, providing real-time updates via a mobile application. This approach not only simplifies the management of the system but also promotes the adoption of technology-driven agriculture in limited spaces, such as urban apartments and condominiums.

Moreover, the project showcased its contribution to sustainability by utilizing a solar-powered energy source, significantly reducing dependency on traditional power sources. This approach aligns with the global need for environmentally friendly and energy-efficient solutions in agriculture, promoting sustainable practices while addressing challenges such as deforestation and limited soil availability in urban areas. The project highlights the potential for cost-saving and self-sufficient food production, particularly for households in need, making it a valuable innovation for the future of agriculture

5.2 Future Works

This project has successfully demonstrated the feasibility of a solar-powered soilless cultivation system, but there are several opportunities for further enhancement. Future work could focus on integrating additional sensors, such as Total Dissolved Solids (TDS) and nutrient concentration sensors, to improve the precision and effectiveness of monitoring plant health and nutrient levels. This would ensure even better control over the growth environment.

To improve scalability, the system can be made modular, enabling users to expand or customize it based on their space and requirements. Another area of development is optimizing the energy efficiency of the solar power system by utilizing more advanced solar panels or batteries and incorporating smart algorithms to manage energy use effectively. Additionally, introducing crop-specific growth algorithms could enable users to grow a wider variety of plants within the same system.

Enhancements to the IoT application can include historical data analysis, allowing users to track and understand plant growth trends over time. Customizable alerts and recommendations for water, nutrients, or pH adjustments could also be added to make the system more interactive and user-friendly. These improvements will make the system a more robust and sustainable solution for small-scale indoor cultivation, contributing significantly to urban agriculture and food security.

Future developments could also include wireless energy transfer technologies to eliminate the need for direct connections, making the system more compact and user-friendly. This would further enhance its practicality for indoor use and small spaces.

5.3 Project potential

The potential applications of this system are vast, particularly for urban households and communities facing space and resource constraints. This system provides a practical solution for those living in apartments or condominiums to grow fresh vegetables like lettuce and Centella Asiatica without soil, contributing to food security and cost savings. Additionally, it promotes sustainable urban agriculture practices by utilizing renewable energy and minimizing water usage, aligning with environmental sustainability goals.

From a community perspective, this project addresses the growing need for localized food production in densely populated areas. It enables individuals and families to grow their food, reducing reliance on market supply chains and contributing to healthier diets. The compact design also makes it accessible for schools, community centers, and small businesses to adopt, promoting agricultural education and self-sufficiency.

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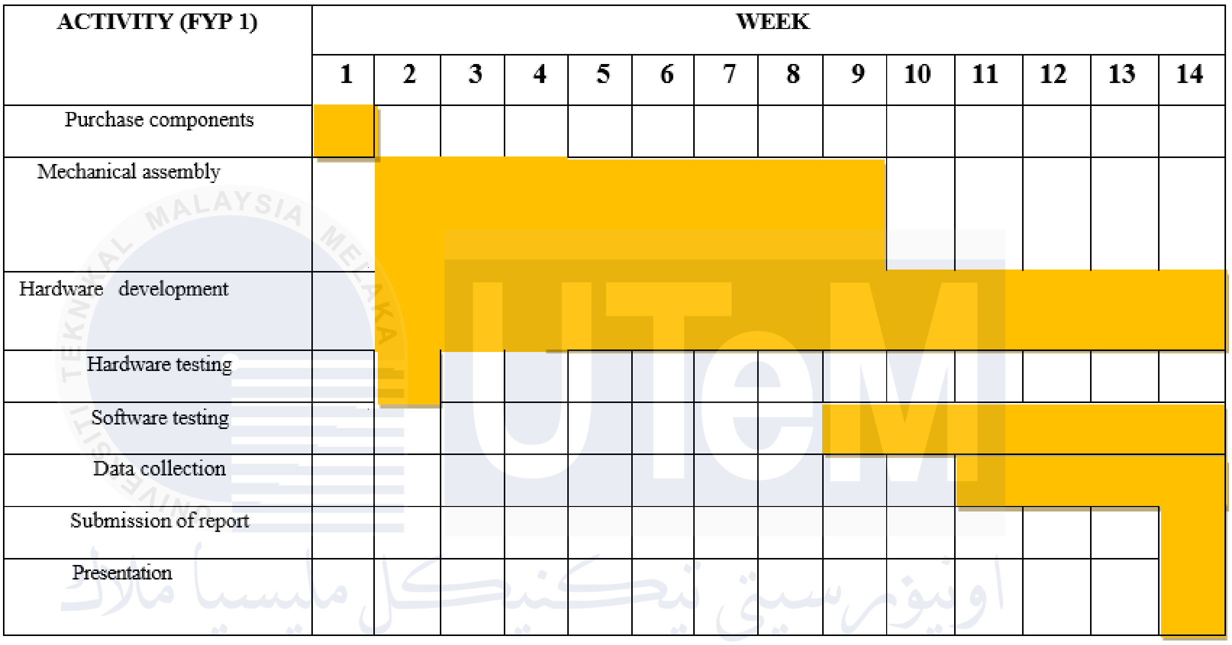
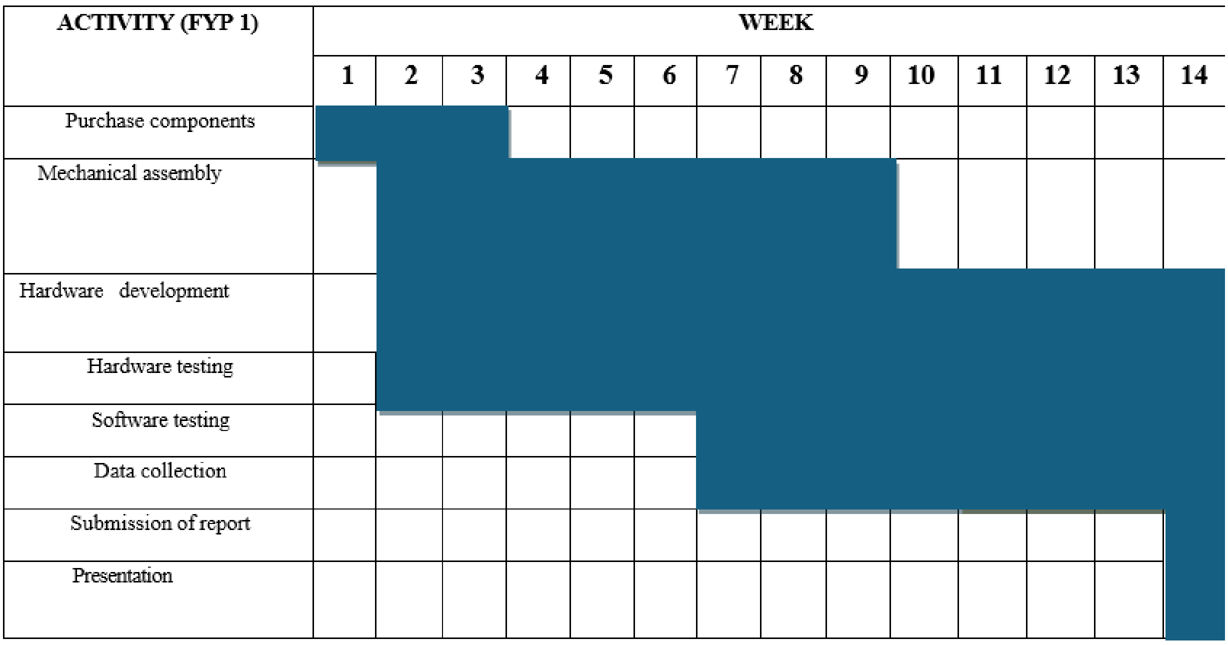
APPENDICES

APPENDIX 1 Gantt chart

Gantt chart PSM1



Gantt chart PSM2



APPENDIX 2 Project code

APPENDIX B PROJECT CODE

```
#include <LiquidCrystal_I2C.h>
#include <Wire.h>
#include <DHT.h>
#include <WiFi.h>
#include "BluetoothSerial.h"
/* Check if Bluetooth configurations are enabled in the SDK */
/* If not, then you have to recompile the SDK */
#if !defined(CONFIG_BT_ENABLED) || !defined(CONFIG_BLUEDROID_ENABLED)
#error Bluetooth is not enabled! Please run `make menuconfig` to and enable it
#endif

BluetoothSerial SerialBT;

#define REPORTING_PERIOD_MS     2000

#define DHTTYPE DHT22 // DHT 22
#define dhtpin 13
#define waterpumppin 14
#define phpumppin 27
#define growledpin 16
#define waterlvlpin 39//2
#define crntsenpin 36//4
#define phsenpin 35
#define ldrsenpin 34
String tosend="satu";
// set the LCD number of columns and rows
int lcdColumns = 20;
int lcdRows = 4;
LiquidCrystal_I2C lcd(0x27, lcdColumns, lcdRows);
DHT dht(dhtpin, DHTTYPE);
float Temperature;
float Humidity;
/*-------------------------------------------------------*/
// Variables for Measured Voltage and Calculated Current
double Vout = 0;
double Current = 0;

// Constants for Scale Factor
// Use one that matches your version of ACS712

const double scale_factor = 0.185; // 5A
// Constants for A/D converter resolution
// Arduino has 10-bit ADC, so 1024 possible values
// Reference voltage is 5V if not using AREF external reference
// Zero point is half of Reference Voltage
```

```
const double vRef = 5;
const double resConvert = 4096;
double resADC = vRef/resConvert;
double zeroPoint = vRef/2;
/*-------------------------------------------------------*/
unsigned long int avgValue;  //Store the average value of the sensor feedback
int buf[10],temp;
int wlvl=0,LDR_Vp=0;
float phValue=0;
uint32_t tsLastReport = 0;
String lightstat="";
void setup() {
  // put your setup code here, to run once:
  Serial.begin(9600);
  /* If no name is given, default 'ESP32' is applied */
  /* If you want to give your own name to ESP32 Bluetooth device, then */
  /* specify the name as an argument SerialBT.begin("myESP32Bluetooth"); */
  SerialBT.begin();
  Serial.println("Bluetooth Started! Ready to pair...");
 // pinMode(dhtpin, INPUT);
  dht.begin();


  Serial.println("Initializing...");
// initialize LCD

  lcd.begin();
  // turn on LCD backlight
  lcd.backlight();
  lcd.home();
  lcd.setCursor(0, 0);
  lcd.print("SOLAR POWERED IOT");
  lcd.setCursor(0, 1);
  lcd.print("  HYDROPONIC");
  //lcd.clear();
  pinMode(waterpumppin, OUTPUT);
  pinMode(phpumppin, OUTPUT);
  pinMode(growledpin, OUTPUT);
  pinMode(ldrsenpin,INPUT);
  digitalWrite(waterpumppin,HIGH);
  digitalWrite(phpumppin,HIGH);
  digitalWrite(growledpin,HIGH);
  delay(1500);

  lcd.clear();
```

```
for(int i = 0; i < 1000; i++) {
        Vout = (Vout + (resADC * analogRead(crntsenpin)));
        delay(1);
      }
    // Get Vout in mv
        Vout = Vout /1000;

      // Convert Vout into Current using Scale Factor
      Current = (Vout - zeroPoint)/ scale_factor;
      Serial.print("Vout:");Serial.print(Vout);Serial.print("V");
      Serial.print(" Current:");Serial.print(Current);Serial.print("A");
      Serial.print(" ");
lcd.home();
lcd.setCursor(0, 2);
lcd.print("Solar Voltage:");
lcd.setCursor(14, 2);
lcd.print((Vout),1);
lcd.print("V");

int wlevel=analogRead(waterlvlpin);
wlvl=map(wlevel, 2000, 4095, 0, 100);
if(wlvl<0)
 wlvl=0;
Serial.print(" wlevel:");
 Serial.print(wlvl);

lcd.setCursor(0, 3);
lcd.print("Water Lvl:");
lcd.setCursor(10, 3);
lcd.print(wlvl);
lcd.print("%");

Humidity = dht.readHumidity();
// Read temperature as Celsius (the default)

Temperature = dht.readTemperature();

// Check if any reads failed and exit early (to try again).
if (isnan(Humidity) || isnan(Temperature) ) {
  Serial.println(F("Failed to read from DHT sensor!"));

}
else {
  Serial.print(F("Humidity: "));
```

```
  Serial.print(Temperature);
  Serial.print(F("°C "));
  lcd.setCursor(0, 0);
  lcd.print("Humid:");
  lcd.setCursor(6, 0);
  lcd.print(Humidity,0);
  lcd.print("%");
  lcd.setCursor(0, 1);
  lcd.print("Temp:");
  lcd.setCursor(5, 1);
  lcd.print(Temperature,1);
  lcd.print("C");

  }
  for(int i=0;i<10;i++)       //Get 10 sample value from the sensor for smooth the value
  {
    buf[i]=analogRead(phsenpin);
    delay(10);
  }
  for(int i=0;i<9;i++)        //sort the analog from small to large
  {
    for(int j=i+1;j<10;j++)
    {
      if(buf[i]>buf[j])
      {
        temp=buf[i];
        buf[i]=buf[j];
        buf[j]=temp;
      }
    }
  }

  avgValue=0;
  for(int i=2;i<8;i++)                      //take the average value of 6 center sample
    avgValue+=buf[i];
//   phValue=(float)avgValue*5.0/4096/6; //convert the analog into millivolt
  phValue=(float)avgValue*3.30/4096/6;
  phValue=3.5*phValue;
  if(phValue<0)
  phValue=0;
  else if(phValue>14)
  phValue=14;
  lcd.setCursor(10, 1);
  lcd.print(" PH:");
  lcd.setCursor(14, 1);
  lcd.print(phValue,1);
```

```
    } //turn on pump ph chemical
  else if(phValue>5) //not acidic
  {

    digitalWrite(phpumppin,HIGH);
  } //turn off pump ph chemical
  if(LDR_Vp==LOW) //sunny day
  {
    digitalWrite(growledpin,HIGH); //turn off LED grow light

    lcd.print("HIGH");
    lightstat="HIGH";
  }
  else if(LDR_Vp==HIGH) //night @ no light
   {
    lcd.print("LOW ");
    digitalWrite(growledpin,LOW);//turn on LED grow light

    lightstat="LOW";
    }
  if(Vout>1000)//Solar output above 1V sunny day
   {
    //charge battery
    }
   else if(Vout<1000)//Solar output below 1V no sun
   {

    }

if (millis() - tsLastReport > REPORTING_PERIOD_MS) {

//  Firebase.setString(firebaseData,"/monitoring/water_level",wlvl);
//  Firebase.setString(firebaseData,"/monitoring/humidity",Humidity);
//  Firebase.setString(firebaseData,"/monitoring/Temp",Temperature);
//  Firebase.setString(firebaseData,"/monitoring/light",lightstat);
//  Firebase.setString(firebaseData,"/monitoring/ph",phValue);
//  Firebase.setString(firebaseData,"/monitoring/voltage",Vout);


  tosend="water:"+String(wlvl)+",humidity:"+String(Humidity)+",temp:"+String(Temperature)
  SerialBT.println(tosend);
        tsLastReport = millis();
 }

//  delay(1000);
}
```